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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

NOTICES.

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Issue of Journal. Notice of the publication of each part of the Journal is contained in the first subsequent circular issued to the members, and in case of non-receipt, immediate intimation should be given to the Secretary. Duplicate copies of any parts can only be supplied to members on payment of 5s. each, plus postage; but cannot even then be had if the parts have been bound into volumes.

The Memorandum and Articles of Association, and the By-laws and Regulations of the Institution were published in the first issue of the Journal, and will in future be published in the first issue of every session.

Changes of Address. It is particularly requested that members notify the Secretary immediately, of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications, unless distinctly stated to be otherwise, in which case full reference to the previous publication should be given.

The Library. By the munificence of the London & Thames Haven Oil Wharves, Ltd., represented on our Council by Mr. A. C. Adams, our library has been handsomely furnished, and is now available for reference by members.

A list of books previously presented to the library of the Institution was published in No. 2, and a further list is appended.

Additional gifts of books will be highly esteemed.

BOOKS RECEIVED SINCE THE ISSUE OF NO. 2.

CASSIER'S ENGINEERING MONTHLY, vol. xlvi, nos. 5, 6: vol. xlvii, nos. 1, 2, 3.
From Arthur W. Eastlake.

GAS AND OIL POWER, vols. viii, ix (1912—1914).
From the Publishers.

IMPERIAL INSTITUTE, BULLETIN, vol. xii, no. 4.
From the Director.

INDIA, GEOLOGICAL SURVEY, RECORDS, vol. xliv, no. 3 (1914).
From the Director.

IRON AND STEEL INSTITUTE, JOURNAL, vols. lxxxix, xc.

——— Abridged Catalogue of the Library, 1914.

——— Charter, Bye-Laws and List of Members, 1914.
From the Secretary.

MINING MAGAZINE, vol. xii, no. 2 (1915).
From the Publishers.

ROYAL SOCIETY OF ARTS, JOURNAL, vol. lxiii, nos. 3239—3251.
From the Publishers.

STEAM ENGINE, A MANUAL OF THE, by ROBERT H. THURSTON, A.M.
From Basil F. N. Macrorie.

THE STEAM ENGINE USER, by various writers, edited and arranged by R. SCOTT BURN.
From Basil F. N. Macrorie.

Subject List of Works on Peat, Destructive Distillation, Artificial Lighting, Mineral Oils and Wares, Gaslighting and Acetylene, in the Library of the Patent Office, 1911.
From the Librarian.

Advertisements in the Journal. A limited number of advertisements of firms interested in the Petroleum Industry, may be inserted in the Journal. Applications for terms, etc., should be made to the Secretary.

LIST OF ADVERTISERS.

(Members are desired, when making enquiries or placing orders with advertisers, to mention that they have seen their announcement in the Journal).

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PERSONAL NOTES OF MEMBERS, AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

In accordance with our announcement on p. viii of our last issue, we here give a short

Sketch of the Life of the late Mr. W. H. MacGarvey.

Mr. MacGarvey was born on the 27th November, 1843, at Huntingdon, in the Province of Quebec, and died on the 28th November, 1914, at Vienna, just completing the 71st year of his useful life.

Leaving Wyoming, Ont., at the age of 23, he removed to Petrolea, where the discovery of petroleum, made in 1865, had greatly interested and fascinated him, and in a very short time he was recognised as one of the most successful pioneers of the Canadian Oil Industry. He rose to great eminence, and was Mayor of Petrolea in 1876. About this time he became interested in politics, and was the Conservative candidate for Parliament for the County of Lambton, and although he was unsuccessful in his candidature, he had the satisfaction of receiving more votes than had previously been obtained by any Conservative candidate.

In 1880 Mr. MacGarvey undertook, on behalf of the Federal Government of Canada, the management of an expedition to the Canadian North West, for determining the area of the coal deposits, and, although the mission was looked upon as an impossible one, owing to the difficulty in transporting heavy machinery across unexplored country, it was highly successful, in spite of great privations.

In 1881 Mr. MacGarvey came to England at the request of Mr. John S. Bergheim, who was anxious to obtain his advice in exploring for petroleum in Hanover, and after returning to Canada to obtain the necessary plant and expert Canadian drillers, he proceeded to Germany, and commenced exploratory operations on the oil lands of that country. From that time to the present Mr. MacGarvey has been recognised as the pioneer, in Europe, of the Canadian drilling system; a system which will ever be closely associated with his name. A warm and close acquaintance sprang up between these two oil pioneers, which remained unbroken until the untimely death, in September, 1913, of Mr. Bergheim.

After conducting many successful drilling operations in the German fields, Messrs. Bergheim and MacGarvey decided to stake their fortunes in the then little-known Galician oil-fields, Mr. MacGarvey making his first essay in Central Galicia, at Uherce, and in these early days Messrs. Bergheim and MacGarvey successfully overcame all the manifold difficulties which the oil pioneer encounters in the opening up of unexplored country.

The first considerable success which Mr. MacGarvey and his partner, Mr. Bergheim, obtained, was the discovery by them of the Weglowka oil district in West Galicia, this success being the forerunner of many others throughout the length and breadth of Galicia, which made the name of Bergheim and MacGarvey known throughout European oil circles.

In due course Messrs. Bergheim and MacGarvey erected the largest petroleum refinery in Europe, outside of Russia, and prided themselves on paying for it out of the proceeds of their business.

In 1895 the business of Messrs. Bergheim and MacGarvey was formed into a limited company, the now well-known Galizische Karpathen Petroleum-Aktien-Gesellschaft, which soon began to extend its operations, and widen the scope of its activities, under the presidency of Mr. MacGarvey's old friend Count Gorayski, and, upon the retirement of that gentleman, Mr. W. H. MacGarvey was elected to fill this important post.

From its modest beginning the Galizische Karpathen Company rapidly grew in importance under Mr. MacGarvey's guidance, and now exercises a paramount influence over the whole Austrian petroleum industry. In addition to controlling a very large proportion of the crude oil produced in Galicia, the company owns, besides its original refinery at Glinik Maryampolski, other refineries in the dual monarchy.

Although the guiding spirit of this vast enterprise, in which he was ably assisted by his son, Mr. F. J. MacGarvey, he found time only a few years ago to undertake a visit to the Maikop fields, where he formed the opinion that the lower-lying strata should be thoroughly tested by deep drilling.

Mr. MacGarvey was the doyen of petroleum technologists, and a very popular man, respected and beloved by all who had the pleasure of his acquaintance, his modesty, intelligence, generosity and kindness of heart appealing to all who came in contact with him, and his loss will be deeply deplored by his numerous friends in England and Canada, and throughout Austria, where he was so well known.

The Secretary will be glad to learn the present address of Mr. James T. Armstrong, M.Inst.P.T., late of 22, Great St. Helens, London, E.C.

Mr. F. D. Brown, A.M.Inst.P.T., has returned to Mexico.

Mr. A. Duckham, M.Inst.P.T., has left for Trinidad.

Dr. W. Hope Henderson, M.Inst.P.T., is still in California.

Mr. F. A. Holiday, A.M.Inst.P.T., left for Mexico in January.

Mr. S. Lister James, A.M.Inst.P.T., went to Trinidad in January.

Mr. B. F. N. Macrorie, M.Inst.P.T., has gone to Persia.

Dr. F. Mollwo Perkin, M.Council Inst.P.T., is visiting the United States.

Mr. W. Sutton, M.Inst.P.T., who has been in the United States, is now in Mexico, and is expected in London at the beginning of April.

Mr. Kenneth Watts, Stud.Inst.P.T., has returned from Russia.

The following gentlemen have been nominated for membership, subject to confirmation by the Council:—James Solomon Blanckensee, Robert Bertram Grey, George T. Holloway, Francis Russell, Stephen Frank Stackard, Carter White.

MILITANT MEMBERS OF THE INSTITUTION.

We had proposed to insert in this issue a list of Members of the Institution who have been able to respond to their Country's call for personal service, and have joined His Majesty's forces in one or another of the several subdivisions of the Navy or Army.

But we feel that it would be altogether invidious to mention the individual cases of such patriotic devotion which happen to have come to our personal knowledge, and we are therefore reluctantly compelled to postpone publication of the desired list until we have reason to believe that it at least approaches completeness.

Meanwhile we would ask all members and other readers to be so kind as to communicate to the Secretary the names, and, where possible, other particulars, of members whom they may know to have thus offered themselves in defence of our national well-being.

Review.

The Chemistry of Petroleum and its Substitutes, a Practical Handbook, by Drs. C. K. Tinkler and F. Challenger. Pp. 368. 8vo, London (*Crosby Lockwood & Son*), 1915.

It is impossible to read the excellent handbook on the Chemistry of Petroleum and its Substitutes, by Dr. C. K. Tinkler and Dr. F. Challenger, without being impressed with the scope which exists for the application of science in the treatment of petroleum.

The University of Birmingham was the first educational establishment to provide facilities for the systematic study of the technology of petroleum, and it is appropriate that the first treatise on the chemistry of petroleum in its theoretical and practical aspects should have been written by the lecturers in chemistry at that university.

The authors have aimed primarily at providing a text-book for students who desire to become proficient in the chemical technology of petroleum,

and they have admirably achieved their object by a skilful association of theory and practice. They properly consider that no man can become a successful technologist until he has fully mastered the underlying scientific principles of the subject. Hence a large but not disproportionate part of the present work is devoted to the pure chemistry of petroleum, and it is not until he has become fully acquainted with the fundamental principles, and has familiarized himself with the chemical and physical characters of the individual members of the various groups of hydrocarbons of which petroleum is composed, that the student is invited to study the practical applications of this knowledge. It will thus be seen that the book is much more than a mere aggregation of facts, for it is a highly commendable and successful attempt to bridge over the gap between the academic and the practical treatment of the subject with which it deals, and it should do much to pave the way to a better understanding of the intimate relation between pure and applied science, as well as of the extent to which the latter depends upon the former.

It remains to be added that whilst the work will be found of special value to the student it may be read with great advantage by all those whose avocations are directly or indirectly connected with the technology of petroleum, and even by that large section of the public whose interest has been aroused by a recognition of the extent to which petroleum has not only become one of the necessaries of civilized life, but, as the motive power of submarines, destroyers, aeroplanes, dirigible balloons, armoured motor-cars, and army transport vehicles, has revolutionized the art of war.

BOVERTON REDWOOD.

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EDITORIAL.

The Educational Functions of the Institution.

Amongst the many profoundly sage remarks of the quaint and genial essayist MONTESQUIEU, too little read now-a-days, there occurs in the *Esprit des Lois*, book xi, the suggestion that it is not always well so far to exhaust a subject, as to leave little or nothing for the reader to do, the main purpose of writing being less the conveyance of ideas than the inducement of readers to think for themselves. A parallel aphorism imports that the true instructor does not furnish information, but merely guides the student in the personal search for it.

The usual textbooks, scientific or technological, assuredly supply ample material for thought, but do not, as a rule, induce that somewhat rare operation. Their function is to convey, more or less completely, the detailed facts of their subjects, and an epitome of the general laws recognised as the summary of the observed phenomena. The student who merely memorises the contents of such works, without truly assimilating them by his own powers of thought, may triumphantly pass examinations, and be credited with the intellectual grasp which he has not effected, but he will find, in subsequent practice, that Nature abhors, not only vacua, but also uniformity in the filling of space, and that, whether material or its conditions are considered, no large bulk of anything is truly as uniform as the textbooks would seem to assume. The presumption of such uniformity, in the absence of intelligence to meet the actual variety, often leads to disaster. It is well if the result is the cultivation, though tardy, of the intellectual power to go behind the phenomena to their controlling principles, and thus to encounter difficulties with measures taken in accordance with such realisation of their source: the quack attacks *symptoms* (often misread), the physician strikes at their *cause*.

It is in this respect of stimulating thought, rather than of disseminating scientific or technological facts, that this Institution, like others of collateral aim, serves to extend the education of its members. We welcome contributions, from expert and novice alike, whether extensive articles or short notes, inquiry, criticism or other correspondence. Our members, widely scattered, cannot, in

many cases, attend our meetings and take part in discussion of the papers there read, but they are at full liberty, subsequently, to ask for explanations of points that may seem obscure (from the necessary condensation for reading within a limited time), to correct errors of statement, or to criticise deductions. The Institution is in no way committed to corporate acceptance of any views propounded by either the original authors or their critics, and the members (unlike jurymen) are not called upon for unanimity in considering their individual verdicts. Let *brains* decide, when doctors disagree: it is a great deal better for the brains than to have their pabulum supplied ready-digested by Pontifical authority as the only orthodox diet.

This cultivation of the mental powers is certainly the highest and truest educational function within the scope of the Institution, but there are others, more palpable in immediate effect, although of minor importance in reality. We endeavour to keep note of the constant accessions to the enormous bulk of literature relating to the wide range of subjects touching on petroleum, and shall be happy both to give and to receive information of this nature. The bibliography of the Trinidad Oilfields, for instance, appended to Prof. Cadman's article in the present number, is as nearly up-to-date as our present knowledge can make it, but there are probably omissions therefrom, of which some of our members may be able to inform us. By furnishing, as opportunity may arise, either complete or selective bibliographies of special regions or topics, we hold that we may be of service in guiding students to the most important sources of information (using the term student to include all members of the Institution, senior or junior, who may desire such assistance).

We shall be happy also to help, in any way within our power, members residing in regions remote from centres of civilisation, and who may be unable to obtain the desired literature. In cases of sufficient general interest, inquiries will be published with replies.

Lastly, although the rooms at present occupied by the Institution are inadequate to serve as a general rendezvous of members, yet, in special circumstances, interviews between London members and any of provincial or foreign residence can take place there by previous arrangement with the Secretary.

W. H. D.

Second General Meeting.

A Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Thursday Evening, 17th December, 1914, Sir Boverton Redwood, Bart., D.Sc., F.R.S.E. (President), occupying the Chair.

The Members of Council present were Mr. Alfred C. Adams, Mr. Edwin R. Blundstone, Professor John Cadman, Mr. Arthur W. Eastlake, Mr. T. C. Palmer, and Dr. F. Mollwo Perkin. There was a large attendance of members and visitors, including several ladies. The Admiralty was represented by Sir Frederick W. Black, C.B., Director of Navy Contracts, and Mr. J. C. Clarke; and the Colonial Office by Mr. G. E. A. Grindle, C.M.G.

The President, in opening the Meeting, said it was with great regret that he had to make the formal announcement of the death of one of the Founder Members of the Institution, Mr. W. H. McGarvey, which took place at Vienna on the 28th November. Mr. McGarvey had reached the age of 71, but he was a vigorous man, and he thought that those who were acquainted with Mr. McGarvey's sympathetic nature would not fail to recognise that anxieties connected with the war might have had a great effect in bringing about the end. Mr. McGarvey was personally known to many of the members, and those who were fortunate enough to be intimate with him would, he was sure, feel that they had lost a true friend. His death created in the industry, especially in that particular branch of it with which he was so closely identified, a real void, because there was no one who possessed exactly that knowledge coupled with breadth of view which made him so important a man in connection with the petroleum industry of Galicia, though fortunately his son, Mr. Fred McGarvey, had been able to render him very considerable service for many years past. Mr. McGarvey gained his knowledge of the technology of petroleum in Canada, and, in association with Mr. J. S. Bergheim, who was also known to some of the members, was the pioneer in the development of the petroleum industry of Galicia; and he supposed there never was a

happier partnership than that which existed between those two men, both of whom were of great ability, and each of whom seemed to become stronger for association with the other. It was really instructive to see the interaction of those two master-minds when they were joined in friendly discussion, endeavouring to solve some of the numerous problems which confronted them in the early days of their work. Mr. McGarvey was a man who had the modesty of true genius. He was, nevertheless, essentially a strong man; he was a man of remarkable initiative and personality, having the courage of his convictions, and pursuing his course with the patience and perseverance that were so essential to success in the industry in which the members were interested. He ventured to suggest that Mr. McGarvey's life and successful career afforded an object lesson which might be usefully pondered over by the younger members of the Institution.

Passing to the subject of the arrangements that had been made for the future Meetings of the Institution, he had the gratification of announcing that Mr. E. H. Cunningham Craig had kindly consented to give an address on the subject of "The Prospective Oil Fields of Western Canada," on Thursday, 21st January, 1915. He presumed that Mr. Cunningham Craig would then give some interesting information based upon his recent experience in that country. For February a paper had been promised by Mr. William A. Hall, the research chemist, dealing comprehensively with the subject of the cracking of oils, with a view to obtaining motor spirit and other products. Papers were also in hand by Mr. William Calder on "Oil Well Engineering," and by Dr. Charles Newton Gould on "The Mid-Continent Oil Fields of the United States," so that the members would see that there was plenty of intellectual food in store.

The communication which Professor Cadman was about to make would, the members would be glad to learn, take the form of a lecture, illustrated by lantern slides, and he was quite sure that as the author had only recently returned from one of his many visits to the island of Trinidad, he would give not only an interesting discourse, but an exceedingly instructive one. Professor Cadman needed no introduction to the members, and therefore without further remark he would call upon him to deliver his lecture.

The following lecture, illustrated by lantern slides, was then delivered:—

Notes on the Development of the Trinidad Oilfields.

By John Cadman, D.Sc., M.Inst.C.E., *Member.*

In submitting to the Members of the Institution the following notes upon the Development of the Trinidad Oilfields, the writer's object is to direct attention to information which has already been published, and to endeavour to illustrate a few of the many difficulties that have been met with in prospecting this important field.

Indications of petroleum have been known for over a century, although the significance of this evidence was not understood, and historical references to the subject are to be found amongst the writings of Dr. Nicholas Nugent (1809), Sir Alexander Cochrane (1809), Mr. Edmonstone Hodgkinson (1824), Messrs. Wall & Sawkins (1859), and others.

When, however, petroleum became of commercial value, attention was drawn to Trinidad as a possible source of supply, and upwards of 30 years ago, a well was put down in the neighbourhood of Aripero, and one a little later at La Brea. A trace of oil was discovered at the former, and a thick, sticky liquid obtained from the latter, but the quantity was considered insufficient to warrant further investigation.

No really serious attempt appears to have been made to test the oil possibilities of the Island, until Mr. Randolph Rust obtained, in November, 1902, a licence to prospect a tract of country in the neighbourhood of Guayaguayare. With characteristic energy, he convinced his associates that drilling was necessary to demonstrate that "Trinidad possesses Oilfields of Imperial importance," and late in 1902 he commenced his first well, proving the existence of a productive sand at a depth of 1000 ft. In the following years, 1903 and 1904, four other wells were drilled, and although oil was again discovered, the natural difficulties incident to pioneer work of this character materially belittled the evidence obtained. The drillers, recruited from a class of men who feared neither climate nor geologist, lived and drilled in spots equally unfavourable from either a health or petroliferous point of view. Those interested in the Colony generally looked upon this new venture with suspicion, and had it not been for the persistent perseverance of Mr. Randolph Rust, it is highly probable that this exploration would have terminated.

In 1903 the Government realised the importance of attacking the problem in a scientific manner, and were fortunate in securing

the services of Mr. Cunningham Craig, of the Geological Survey of Scotland, to undertake a geological survey of the Island. In 1904 the writer was appointed Mining Engineer to the Colony.

The work of 1903 and 1904 encountered difficulties which have become more manifest in later years, and although by no means discouraging evidence had been obtained, the enormous expense of prospecting in a tropical forest, in an area only accessible from the shores of the open Atlantic, or actually on the beach at certain stages of the tide, necessitated the suspension of drilling in the Guayaguayare field at the close of 1904.

In February, 1904, Mr. Cunningham Craig presented his first report upon the Guayaguayare Mayaro Oilfields, which was published in Council Paper No. 25 of 1905. This report is the first scientific contribution devoted to the oilfields of Trinidad, and although superseded by subsequent reports will repay the careful perusal of anyone wishing to study the development of the Trinidad Oilfields.

In February, 1905, the Rust licence was extended with some additional area, and formed the Concessions of the Oil Exploration Company of Canada. Drilling operations, conducted by this Company between May, 1906, and June, 1907, were fraught with immeasurable difficulties. Still in a most inaccessible part of the Island, still literally lugging plant through dense vegetation on ill constructed roads, still with drillers careless of the consequence of the mosquito bite, and oblivious of the geological conditions within which they worked, the efforts of the Company, deserving of a better fate, were suspended in 1907.

Early in 1907 the Trinidad Petroleum Company came into the field, and secured licences to prospect in an area hitherto untested, but which had been shown to possess favourable structure and indications, and in a locality more easily accessible from the placid waters of the Gulf of Paria. Drilling operations were commenced at Point Fortin, and have been continued to the present time. The engineering problems encountered in drilling through soft clays and loosely cemented rocks, and the uncertain health of the Staff in the early stages seriously handicapped the progress of this Company.

In 1908, the New Trinidad Lake Asphalt Company entered upon an extensive exploration of its property in the neighbourhood of Brighton and La Brea. The previous experience, obtained in connection with the successful manipulation of the great Pitch Lake, was an invaluable asset in its favour. Prosecuting their investigation with commendable activity, it was not long before substantial

proof of the potentiality of the oil resources of the area was forthcoming.

It is impossible to refer to all the energy and enterprise that has been put into the Colony during subsequent years, but the early work done by the Companies referred to is deserving of special note, as such work, whether successful or unsuccessful, has been of national importance in figuratively breaking the ice in a difficult region to investigate.

Any reference to the early exploration of the field would be incomplete without a tribute to the indomitable activity of my former colleague Mr. Cunningham Craig, whose pioneer geological work stands as a foundation upon which all subsequent work has been based. His clear and striking accounts of the petroliferous conditions existing in Trinidad have done much to promote the development of the oilfields.

This historic review would be wanting if a reference were not made to the official stimulation given to the development of the industry by His Excellency Sir Geo. Le Hunte, G.C.M.G., and to the inestimable work done by Mr. A. G. Bell, C.M.G., the Director of Public Works and for a time Inspector of Mines, under whose direction the prospecting licences have been issued. I venture also to refer to those silent workers at the Colonial Office, the Crown Agents Office, and the Admiralty, whose efforts in the development of the oil resources of this British Colony will surely be revealed to future generations, and should not be forgotten. In connection with this official work, the technical skill of our President has also on many occasions been brought to bear upon the subject to its advantage.

The Oil Rocks.—Whilst it is not the writer's intention to review the geological record of work that has been published, he ventures to direct attention to a few salient features in the hopes that a contribution may be added to the discussion by those Members who have assisted in executing the detailed geological examination of the Island. As will be seen from the map, the Island of Trinidad is topographically divided by three ranges of hills, running from East to West. The Northern Range, following the North Coast line of the Island, is composed of metamorphosed rock of so far undetermined age. The Central Range, stretching from Manzanilla Point to San Fernando, consists chiefly of rocks of Lower Tertiary age with isolated exposures of Cretaceous. The Southern Range, traversing the Southern Coast, is of Lower Tertiary origin, although probably a little higher in

horizon than the rocks which compose the Central Range, with here and there pre-Tertiary inliers projecting through the newer rocks.

It is estimated that the thickness of the Tertiary rocks is 6000 to 6500 ft., consisting chiefly of clays, sands and marls, with oil-rocks recognised at three main horizons.

Some confusion has recently occurred in the names given to these horizons, caused no doubt by lack of recognition through variation in thickness and productivity of the sands. It seems unfortunate that the geologists who have recently worked in this field should not retain the names originally given to each horizon, no matter how much they found it necessary to sub-divide the same.

The upper oil horizon is known as the La Brea Sands, which is exposed in the neighbourhood of La Brea, and here gives rise to the Pitch Lake deposit, for which Trinidad has so long been famous. Some 1400 to 1500 ft. below this sand or group of sands appears the second oil-bearing belt, the Rio Blanco Oilsand, and at a further depth of 3600 to 4000 ft., approaching the base of the Tertiary, is to be found the Galeota petroliferous group. A lower horizon is said to have been isolated in the neighbourhood of Tabaquita, but it is questionable whether the bed will not be found to be a member of the Galeota group, when more detailed mapping has been resorted to.

Part of the area lying to the south of the Central Range has been geologically mapped, and its structure more or less worked out. There is, however, much detailed work still to be undertaken before areas can be selected for test drilling. Within this southern area lie the zones which have so far been examined, and in which the development is progressing.

To the north of the Central Range is a tract of flat-lying country covered with alluvium, and it is not improbable that light oils similar to the Tabaquita oil may be discovered here. No work has, however, been done in this locality.

The lateral variation so frequently referred to in the Government reports is always evident, as drilling reveals the sections, and its significance seems to have been misunderstood. It would appear that the rocks are more sandy to the west and south, and more clayey to the north-west and east How far this variation if established will influence the productive areas is still án unsolved problem. The preponderance of successful drilling in the south-west compared with that in the east is interesting in this connection.

The Development of the Fields.—Before referring to the work accomplished in the Island it may be of interest to state that mining tenure in Trinidad is divided into three classes:

(1) Under Crown Lands (waste or vacant lands, chiefly virgin forest).

(2) Under alienated lands, with mineral rights reserved by the Crown.

(3) Alienated land possessing title to the minerals.

The acquisition of mineral rights is obtained in the case of (1) and (2) from the Governor or Intendant of Crown Lands, and in (3) from the owners of the surface. In the latter case the rights are obtained by purchase or agreement. In the other cases the procedure is laid down under the Land Regulations of the Colony.

As Intendant, the Governor issues from time to time regulations for the guidance of the Department of Crown Lands, and it is under these regulations that mining licences are granted. The procedure, as at the present followed, is divided into three stages:

(*a*) The Exploration Licence, which enables a geological examination to be made.

(*b*) The Prospecting Licence, which requires test drilling to be undertaken, and

(*c*) The Mining Lease under which powers are granted for the continuous working of the deposit.

Turning to the tangible evidence of development, the following table illustrate the work done, and production of the oil obtained, during the past 13 years, as published in the official returns. For the years 1902 to 1907, no figures of production are available, all the oil obtained being used for boiler purposes, &c.

These statistics are both interesting and important, for it will be noted that though the rate of development has been slow, there has been a material advance in production during the past three years, and although the figures are not available for the current year, 1914–15, the output has already shown a swelling in volume that is likely to double that of the preceding year. Up to the present time about half the wells have failed to produce, and many that have produced have temporarily ceased to do so, owing to sanding up—a condition to be shortly referred to.

These statistics include drilling in proved and unproved areas, and are largely composed of test wells. Why better results have not been obtained from the wells that have passed into the oil-sands, and why more drilling has not been accomplished in

comparison with the energy and capital expended, are questions which will at once arise. There are several reasons to account for much of the delay, and it is now proposed to review briefly some of them.

No one who has not had experience of the Trinidad tropical forest can realise the difficulties of transport. The making of tracks and roads to enable machinery to be conveyed to the

Year.	Imperial Gallons Output.	Feet Drilled.	Number of Wells.
1902	—	1,015	1
1903	—	2,665	3
1904	—	1,904	2
1905	—	Nil.	—
1906	—	2,229	2
1907	—	2,837	4
1908	5,900*	3,758	4
1909	2,000,000*	5,927	6
1910	5,000,000*	7,321	7
1911	9,985,740	14,485	14
1912	15,288,162	40,418	46
1913	17,626,563	42,552	44
1914	22,523,660	41,933	41
	72,430,025	167,044	174

* Estimated.

drilling sites is no easy matter: indeed this work is almost limited to the dry season, and as much of the early development work was undertaken in places remote from any line of transport, much solid work of this character had to be undertaken before any drilling could be commenced.

Although the residential parts of Trinidad are extremely healthy, the places selected for test drilling were invariably in localities where special precautions had to be adopted to safeguard the health of the imported staff. The conventional and established methods of preventing the spread of malaria were frequently attended to in an indifferent manner, and it was not unusual to

FIG. 13.—Oil spouting from a well, showing deposit of sand in foreground, blown out with the oil (United British Oilfields, Limited.)

find a large proportion of the drilling staff incapacitated. Within recent years mosquito-proof houses have been established, with clearing of brush and undergrowth from around the dwellings, which has resulted in a remarkable immunity from malaria. The obstinate individual, however, still exists who imagines such procedure an unnecessary precaution. Much good work has been done to safeguard the health of the staff in the field, but too much

attention cannot be bestowed upon this matter. To expect an army of workers to produce efficient results, without maintaining their labour capacity at the highest pitch, is a failing which has not been sufficiently realised in the past.

The difficult problems which have been encountered in drilling through the soft Tertiary clays and sands have in some measure been surmounted, although in the earlier work attempted in the Colony, the unusually soft and ever caving ground caused much disappointment, many delays, and not infrequent failure.

The occurrence of an oilsand, in itself loosely cemented together, under superincumbent material of similarly unstable characteristics, has been one of the chief difficulties met with in the Trinidad field, and when accompanied with gas under excessive pressure presents a problem of no mean magnitude. To this condition, in varying degrees, is due much of the delay in obtaining working productions.

That gas exists under enormous pressure frequently becomes evident in the outburst of mud and stones in great violence from several of the numerous mud-volcanoes found in the southern part of the Island.

The Columbia mud volcano, for example, occasionally exhibits most violent conditions, when tons of plastic clay, with fragments of sandstone and shale, are hurled hundreds of feet into the air by the force of the escaping gas.

Again, the gas pressure existing in the oilsands became manifest on the 4th and 5th of November, 1911, when an island suddenly made its appearance in Erin Bay some two miles south of Chatham. The island was first noted on the 4th, when it appeared to cover about an acre in extent, and two mud volcanic cones some 20 ft. in height were visible. On the following evening a violent eruption took place, so violent indeed that its shock was felt at Cedros, 18 miles away. The enormous volumes of inflammable gas which poured out on the eruption, became ignited, probably by sparks from abrasions of pyritic fragments, and the flame extended to a height of 300 ft. The flame appears to have burnt for some 15½ hours before it subsided and became extinguished. On examination the island was found to occur on the crest of an anticline, previously mapped by the Government Geologist, to be oval in shape, to cover 12,000 sq. yds., and to be 10 ft. above sea level. The surface of the island was composed of sand, mud, fragments of pyritic material and oilsands.

The great volume of gas under enormous pressure that was necessary to produce such an outburst, will at once be realised.

It is not therefore surprising that drilling should encounter gas pressures which are difficult to handle.

Gas pressure has already become very serious in the case of the Trinidad Lake Petroleum Company's operations in the Vessigny field, where 11 wells have been drilled to a depth of some 1400 to 1800 ft., to the Rio Blanco Oilsand which has here been found to be of considerable thickness and to contain gas under heavy pressure. To such an extent did the gas interfere with the operations of drilling, that it became almost impossible, with the plant available, to keep the wells under control. In a similar, although less-marked degree, all the initial drillings which intersected the productive oilsands in the South-West of the Island, have been seriously handicapped by the sanding up of the wells under gas pressure.

As the Vessigny case illustrates a real difficulty in the development of the field, I may be permitted to describe the operations and methods adopted with a view to overcoming the same.

In prospecting drilling, the standard cable tools were employed, 15½ in. casing being used in the first 500 to 600 ft., which was then "cemented in" to shut off the surface water. 12½ in. casing was carried forward to some 1400 or 1500 ft., when the first gas under pressure was encountered, which exhibited sufficient energy to blow the tools and water out of the well, followed by a flow of oil, containing sand in large proportions. Periodic choking of the hole with loose sand followed, and when an attempt was made to introduce a string of 10 in. perforated casing to enclose some 20 ft. of the hole existing below the 12½ in. casing a literal bombardment of the bottom of the hole resulted in collapsing and buckling the casing, so as to prevent the hole being carried through the sand.

Having proved the position of the oilsand, the hydraulic rotary flush system of drilling was adopted in subsequent holes, and in this portion of the field the 10 in. casing was usually landed in to the upper few feet of the oilsand, but invariably the gas pressure was too excessive to permit of the completion of the well and the casing became bent and distorted in spite of the heavy material used. Thick mud was used during the drilling, and a pressure of from 80 to 100 lbs. per sq. in. applied at the pumps. This difficulty has not yet been satisfactorily solved, although it is likely that with the application of blow-off preventers and large mud pumps, with a working pressure of 200 to 300 lbs. per sq. in., and thick mud, these wells will eventually be brought under effective control. The engineering difficulties in "drilling in"

a well with gas under excessive pressure when the strata are of a loose and friable nature, are well known. These difficulties have been met with and overcome in the Californian fields, particularly at Coalinga. Some of the Trinidad fields surpass the Californian fields in difficulties arising from this source. The Colony, and the Trinidad Lake Petroleum Company are, however, fortunate in having an engineer of Mr. McKnight's experience attacking this important question. New conditions have been revealed, which require plant of special strength and construction to deal with them successfully.

The effective control of the wells drilled into loose and friable oilsands is a problem which has exercised the attention of engineers in charge of the Trinidad fields, and much valuable work has now been accomplished, although, in the early investigation, it was a source of frequently serious disappointment. The crude oil, carrying with it large volumes of sand, unless effectively dealt with, sooner or later partially or entirely blocks the well.

Where production has been established, and where the wells are under control, the admixture of sand with the oil presents a problem of serious economic importance.

The procedure adopted is to allow the sand to settle out (by gravity) in an open sump, from which the clarified oil is decanted to the storage tanks. With an oil carrying 10 % of sand, this open method of settling entails a loss of from 2 % to 3½ % of volatile oil from the original volume, which evaporates under the action of the tropical sun. The problem of separating the sand from the oil without the loss of so much valuable product is one which has not yet been economically and efficiently solved. More frequently than not, the oil gushes out of a well when the oilsand is tapped, bringing with it a large percentage of sand, which is deposited around the derrick and in the sumps in which the oil is received (Fig. 13, p. 105). As much as 25 % to 30 % of sand may issue with the oil for the first two or three days, after which up to 10 % or 15 % comes away for a period of from two to four months, when the well settles down to producing oil comparatively free from sand.

So far there is no reliable evidence concerning the life of the wells. A comparatively large production in the initial period is generally obtained, which decreases by 40 % to 50 % after a period of two or three months, when the volume assumes a steady amount, where "sanding up" can be avoided. A typical characteristic curve is attached, the spurts in production being accounted for by periodic cleaning of the wells.

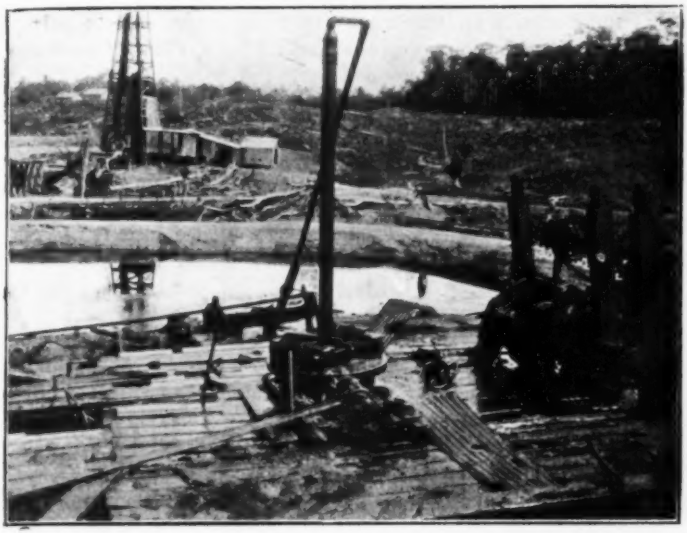


FIG. 14.—Open sump, in which sand settles out of oil (Trinidad Lake Petroleum Company).

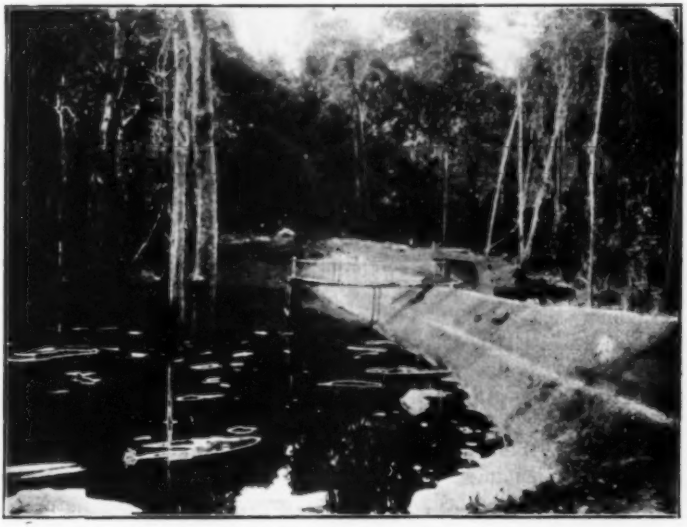


FIG. 15.—Open storage filled with oil in the Trinidad Forest Reserve (Trinidad Leaseholds, Limited).

A number of wells, which may be looked upon as test wells, have continued to produce in this manner for upwards of three or four years, and are still producing.

The details of two historic wells, which have already been published, deserve special note: the Stollmeyer well, and No. 42 Vessigny. The former, drilled in June, 1912, some 300 ft. into the Rio Blanco horizon on the Morne L'Enfer Forest Reserve Anticline, had an initial production of over 100,000 gal. per day. This was an exploratory well, and was for a time entirely out of control. It has, however, produced with regularity, and, after two years, is producing at the rate of 5000 gal. per day, no serious attempt having been made to increase its productivity.

No. 42 in the Vessigny field, at a depth of 1943 ft., gave, from the Rio Blanco horizon, an initial flow of over 1,000,000 gal. per day for several days, when the well unfortunately became ignited by the alleged carelessness of a labourer lighting a match within the danger zone. The fire was ultimately extinguished by the well sanding up and ceasing to flow.

Although there are quite a number of wells which show promise of a substantial life at high productions, there are also wells giving small productions, which show signs of continued productivity. The latter is particularly the case in the wells producing the light oils from the lower horizons.

Quality of the Oils.—With the quality of the oils this paper is not concerned, but it may be stated that from the analyses made by Professor Carmody, the oils so far recovered vary widely in composition, with asphaltic base of sp. gr. 0·975, containing 4 % of petroleum spirit, to an oil of 0·810 sp. gr., containing 40 % of petroleum spirit, the heavier oil being confined to the upper horizons, while the lighter oil appears to be confined to the lower sands.

Although refineries have been constructed on several of the fields, it is only within a comparatively recent period that any attempt has been made to refine Trinidad oil in the Colony, and no refinery has yet been constructed to deal with the product on a large scale. This delay has naturally arisen through lack of production. As the production is now assured, the refining of oil in the Colony will shortly be accomplished with more ambitious dimensions.

Transport.—Similarly with the delay in refining, so the construction of pipe lines for the conveyance of the oil has not, to any extent, been established. Facilities are available in the nature of legislation to enable pipe lines to be constructed for the transport

of a Company's production, and one Company has undertaken Common Carrier obligations.

Conclusions.—The rate of development may not have been as rapid as one might have expected—and in some respects there may be room for criticism—there is, however, no doubt that much good work has been accomplished, many difficulties have been overcome, many new problems have been solved, and sufficient work has been accomplished unquestionably to demonstrate the potential value of Trinidad as a source of petroleum.

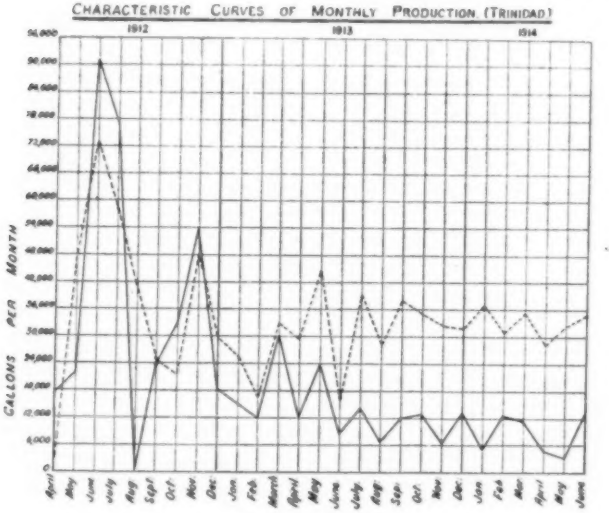
FIG. 16.—The Morne L'Enfer Forest Oilfield, showing nature of clearing prior to drilling (Trinidad Development Company, Limited).

The lessons which have been learnt in the development of the Trinidad Oilfields indicate that drilling should be undertaken only after a minutely detailed geological survey has been accomplished, that plant of substantial design only should be used, that a staff of more than rule-of-thumb practitioners should be employed, and that they should live under conditions suitable to the climate, obeying the laws of health which a tropical country demands.

With the activity now being pursued by such Companies as The Trinidad Lake Petroleum Co., The Trinidad Leaseholds, Ltd., The United British Oilfields, Ltd., The United British West India

Petroleum Syndicate, The Trinidad Central, The Cruse Syndicate, The Venezuelan Oil Exploration Co. and Messrs. Stollmeyer, who are all producing oil at the moment, the future of the Oilfields of Trinidad is assured.

Lastly, the writer wishes to express his indebtedness to Mr. W. H. Dalton for much of the appended Bibliography.



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DISCUSSION.

The President said the subject of the admirable lecture, to which he was sure all the Members had listened with great pleasure and profit, was one of exceptional interest to Britishers, because Trinidad offered, he thought he might say definitely, the most excellent prospects of proving to be an important source of petroleum under the British flag. In common with the so-called tar of the adjacent island of Barbados, the pitch of Trinidad had been known for many centuries. The famous Pitch Lake of Trinidad, which the lecturer had referred to as one of the wonders of the world, was visited by Sir Walter Raleigh in March, 1595, and only that afternoon the speaker had come across the following quotation from Sir Walter's record in reference to that lake, the statement being made that Sir Walter saw there "that abundance of stone pitch that all the ships in the world might be laden from thence, and we made trial of it in trimming our ships and found it to be excellent good, and melteth not with the sun as the pitch of Norway." It was also interesting to note that Gesner, in his treatise on coal and petroleum, which was published in New York in 1861, stated that it was from the pitch of Trinidad that he first made kerosene, and that an American company established a refinery in the island, for the manufacture of burning and lubricating oils in 1858, a year before the petroleum industry of the United States as it now existed had its birth in the successful completion of what was known as the Drake well. It was also worth mentioning, in connection with the successful work carried out by the Trinidad Lake Asphalt Company, that for a long time there was vigorous opposition to any attempt to drill for petroleum in Trinidad, at any rate within a mile or two of the celebrated Pitch Lake, and he remembered

being consulted a great many years ago by the then Governor of Trinidad on the subject. There was no doubt that if it had not been for the apprehensions of the concessionaires of the Pitch Lake, that if any drilling for oil was allowed the source of their pitch would be tapped, there would have been some development of the petroleum industry, at least in that part of the island, at a very much earlier date. From his personal knowledge he wished in the strongest terms to endorse what the lecturer had said of the services which were rendered by Mr. Randolph Rust, whom he frequently met in the earlier period of his pioneer work in connection with the Oil Exploration Company of Canada, the holders of the Guayaguayare License granted in 1902. He thought he might fairly say that it was mainly owing to the infectious optimism of Mr. Randolph Rust, coupled with his remarkable perseverance, that the initial difficulties were overcome. To Mr. Cunningham Craig great credit was also due, because it required some amount of personal courage to undertake the responsibility that was involved in writing his first very encouraging report on the basis of what he thought Mr. Cunningham Craig would himself admit to be perhaps somewhat scanty data. He proved, however, to be substantially right. It was quite clear, from the particulars which had been given by the lecturer, that there were special difficulties attaching to the development of the oil fields of Trinidad, but he was quite sure that no one could have listened to the lecture without being convinced that those difficulties were in course of being overcome, and that Trinidad as a source of oil was a national asset of the highest value to the Empire.

The Institution was fortunate in having present at the Meeting many gentlemen who were competent to add to the knowledge of the subject which had been dealt with by Professor Cadman. How far they might be induced to enlighten the members he did not know, but, as a first attempt, he would call upon Mr. Cunningham Craig to narrate something of his own personal experiences in relation to the matter.

Mr. E. H. Cunningham Craig said that he had listened with the very greatest pleasure to the most interesting address that had been delivered, and had looked with perhaps even greater pleasure at the beautiful pictures that had been thrown on the screen, depicting scenes of bustle and industry in places where, when he first saw them, there was nothing but dense bush and high woods. He took a special interest in the subject because it was in Trinidad that he first began to study petroleum.

When he first went out to Trinidad as the Government geologist, very little was thought of the petroleum prospects of the island. He was told before he went out by authorities in this country that although some people, especially the optimist, Mr. Randolph Rust, believed there was petroleum in Trinidad, nothing would ever be made out of it. He was employed chiefly by the Government in Trinidad to study the coal deposits that had recently been discovered, which were thought very highly of, and also to deal with the question of the water supply: the question of petroleum was a mere afterthought or a side issue which it was suggested might be taken up at any time. As luck would have it, having no camp equipment with him when he arrived, and as there were some fairly good camps down on the oil fields, after spending ten days in Port of Spain he left for the Guayaguayare oil fields, perhaps one of the most unfortunate places that could have been selected for the first exploitation of petroleum in the island. Since his first two months in the island of Trinidad he had never had the least doubt about its eventually proving to be a successful oil field. When he first began to study oil he was entirely a greenhorn, and his first report was full of crudities of which he had been very much ashamed ever since. It was published some 18 months after it was written, and he was ashamed of it then, and had been ever since. He had hoped that it would have been buried among the historical records to which the lecturer had referred.

Everyone knew how historical records, especially official reports, were pigeon-holed and put away, and often not looked at again, and he was therefore sorry that the lecturer should have alluded to his (Mr. Craig's) first unfortunate report. The lecturer was in rather a difficulty in discussing the subject of Trinidad as he was the recipient of a great deal of confidential information from various companies, and personally the speaker found himself in exactly the same position.

There was a good deal that might be said about the geology of Trinidad and the discoveries that had been made since 1907 or 1910, but, unfortunately, most of those interesting points were the confidential property of various oil companies, and to speak about them freely would be impossible. He would, therefore, have to content himself with saying a few words about the way the industry had grown, or rather the way in which it had not grown.

A very interesting table had been exhibited by the lecturer showing how the production of oil had steadily increased from

year to year. The production had increased more rapidly in recent years, but anyone who knew Trinidad well, and who knew how many parts had been proved to be petroliferous, and how many successful wells had been drilled—although it must be admitted that a very great number of wells had been unsuccessful, and ought never to have been drilled at all—could not help wondering why progress had not been more rapid.

As the lecturer had pointed out, the clearing of the forest was a difficult matter, as was also getting over the troubles incidental to the sanding up of the wells. For some years past those problems had been studied by competent men; much had been learned, new methods had been tried, and he could not help thinking that a very much greater advance should have been made. In his opinion something more might have been done to encourage the industry than had been the case. The present was, perhaps, hardly the time to rake up the grievances that were brought up by companies, speculators, and oil men, but in view of the many complaints that he had heard, especially from the people living in Trinidad, he could not help feeling that if a little more foresight had been exercised by the authorities in Trinidad, the industry would have been in a better position than it was at the present moment. For instance, he believed that quite recently the Government had stimulated the refining of oil by putting an excise duty upon petrol equal to the import duty on that article. Such action showed what he might call a lack of foresight. He remembered when he discussed those matters in Trinidad with the higher officials he was given the direct undertaking by several of them, including the Governor, that no excise duty would ever be put upon any petroleum product equal to the import duty upon it. He was sorry to see that that promise had been forgotten; it had probably been pigeon-holed among the very voluminous reports and memoranda in the archives of the Trinidad Government. He must not, however, digress into those topics.

He could only repeat again with what great pleasure he had listened to the lecture, and express the wish that he could go out to Trinidad again with Professor Cadman to see the beautiful scenes that had been shown on the screen and even to sleep in the woods, pictures of which had been shown.

Mr. A. Duckham desired in the first place to pay a tribute to the work that Professor Cadman had done in connection with Trinidad. He felt very strongly that the island was greatly indebted to the lecturer, who, by the way, seemed to have learned

the secret of perpetual youth. Not only was Professor Cadman learned in his profession, but he was also a shrewd business man. There was, perhaps, a touch of Lord Kitchener about him, which he would illustrate by telling a story he heard from a more or less official source, which the officials of Trinidad told against themselves. A certain company applied to be allowed to put down tankage for loading steamers. The Government agreed it was quite necessary that permission should be given, and as Professor Cadman was on the island at the time, they consulted him in regard to the decision that should be arrived at. They told him they thought no tank should have a capacity greater than 5 tons. While agreeing with them, Professor Cadman said he thought they had forgotten the 0's, and he proceeded to add three 0's after the 5. He did not know what truth there was in the story, but it illustrated Professor Cadman's characteristics. He believed the ordinance still existed in Trinidad that if 10 gallons of petroleum were moved, it had to be accompanied by a red flag. He suggested that that ordinance should be repealed at the first opportunity.

The lecturer had not mentioned the name of the gentleman who put down the first well in Trinidad, and he thought it was due to his memory that it should be placed on record. He believed he was right in saying it was a Dr. Darwent, whose son was at present a medical practitioner in Trinidad. The well, which was put down some forty odd years ago, was 4 in. in diameter and something over 200 ft. deep. It was nearly covered with jungle at the time of his visit, but it was full of excellent oil which was flowing over, and he had a sample of it in his laboratory.

He thought almost enough had been said in regard to the difficulties connected with the industry in Trinidad, but he saw a gentleman at the meeting who reminded him of some work that was undertaken in connection with that matter. It was decided on one occasion to take particulars for future reference of how long it took to get into the jungle. The gentleman to whom he referred and himself had one nigger with them, who, together with his friend, did the actual work whilst he personally directed operations with a compass, and it was found that it took 1½ hours to cut their way with cutlasses 600 yards. Coming back, the same distance was covered in 10 minutes. That would give the members some idea of the difficulties that were met with in penetrating through the jungle of Trinidad.

With regard to the question of health in the island, he hoped

it would not be considered impertinent if he said he felt very strongly that all companies working in the island would do well if they made it a rule that their white staff should not stay out there too long at a stretch. Instead of keeping a man out for two or three years, and then giving him four or six months' holiday, he thought they would be well advised to bring the white staff back to this country more frequently, say once a year. In the first place, the white staff did not want a very long holiday at home, and, in the second place, the sea trip of a fortnight each way did them far more good than any other holiday. He felt sure that more efficient work would be obtained from the white staff if such a plan were adopted.

Mention had been made of the difficulties of drilling, and the qualities of oil that were obtained. Those points touched him somewhat closely, because in a certain district of the island, where a company with which he was connected was working, they had been remarkably fortunate in those respects. None of the serious troubles had been met with that had been experienced in the asphaltic regions. The ground was considerably harder and held up much better, and the oil was obtained at depths of 300 ft. and 400 ft. So far as the quality of the oil was concerned, it was remarkable that the lowest specific gravity they had yet obtained was 0·794 and the highest 0·812, i.e. relatively 46 and 43 Baumé. The highest content of spirit that had been obtained, boiling under 150° C., was 49 %. A consignment of 100 tons was sent over from Trinidad some time ago for trial, and Sir Boverton Redwood, who tested it, arrived at the figure of 44 %, so that he thought in future Trinidad need not be entirely regarded as an asphaltic oil country.

Very little could be said on the question of the length of life of the wells. On the property to which he referred there were shallow wells, one especially, that yielded oil from a depth of about 400 ft., flowed for one year, and it was then capped, when it was giving about 50 barrels a month of high-grade oil, which was the same rate as after the first three weeks. It was apparent, therefore, that the production of the well had practically not diminished during that period. Another well of some interest was No. 12, which was brought in when he was out in Trinidad during the present year. At a depth of 260 ft. the sand was struck, and whereas, in the well he had previously mentioned, it was only 15 ft. thick, in this it was 106 ft. thick. The oil spouted 150 ft. into the air, but it was capped without difficulty. The latest news he had was that the ground was cracking within a radius of 40 ft.

of the well, and oil was being lost through the fissures, though some was being collected and refined.

He had one grumble to make in regard to Trinidad, and that was to express his disappointment at what had been done by the large companies. The large companies went to Trinidad with a considerable flourish of trumpets, and the small companies were made to feel even smaller than they actually were. They were told that wonderful things were going to be done. When his shareholders said in some dismay, "What do you think about the entrance of these large companies into Trinidad?" he replied that he did not think they need be frightened; they would do a world of good, because they would make Trinidad famous. That, however, was an event for which he was still waiting.

Mr. R. H. McCarthy, C.M.G., said he naturally took a great deal of interest in the subject, because he did not think he claimed too much when he said that his connection with it was probably older than that of anybody present. As a member of the Trinidad Government, it was his lot to be associated with the granting of the first licence, which the lecturer referred to, in 1902, some years before the Government was wise enough to seek the aid of science, and to employ his friends Professor Cadman and Mr. Cunningham Craig. Since that time the industry had made a certain amount of progress, but he had listened to the criticisms made that evening respecting the delay with a considerable amount of sympathy. He did not think it was necessary for him to go very deeply into the causes of the delay, because they had practically all been mentioned. Undoubtedly, one of them was the difficulty attending work in a tropical climate. Another, he was afraid, was due to the fact that a certain amount of disrepute had come upon the Trinidad oil industry by the entry into it, at the time of the boom in 1910, of people whom for the sake of Trinidad it would have been better had they remained out of it. It was difficult for him to say what he wished to say in an assembly largely composed of experts, but, speaking to them in the most friendly spirit, he was inclined to think they were to blame for it too. They were frequently too optimistic, and he could name very many cases where they suggested a sum for working capital which events proved to be thoroughly ludicrous. Not only did persons who were mere adventurers throw discredit on the industry at that time by the course that was adopted, but thoroughly honest small companies in this country were also brought to misfortune through the advice of experts.

He hoped he might be allowed to say, without being considered

impertinent, that he had taken a great deal of interest in the establishment of the Institution, because he thought it would probably help to get rid of persons who, at the time of the boom of 1910, were able to pose as experts through having acquired some of the "patter" of the profession. Secondly, he thought the establishment of the Institution would help to remove something that had been a source of deep mortification to him, namely, the employment of foreigners. He was connected with some oil companies in Trinidad, and it had been most mortifying to hear, time and again, people to whom he was bound to listen say with authority that they could not get the managers or the advisers they wanted in England; it was necessary to go to the Continent of Europe or to America for them.

He could not help thinking that the organisation of the profession which the Institution had undertaken would do a great deal, not only to remove that reproach from the country, but to encourage English capitalists to put their money into the industry in Trinidad and elsewhere. He desired to say, in conclusion, that it was like old times to hear his friends Professor Cadman and Mr. Cunningham Craig pouring out the words of wisdom to which he listened so assiduously and with so much humility in years gone by.

Mr. Beeby Thompson said he had always felt the greatest admiration for Professor Cadman, and he saw no reason to modify that opinion after the lecture he had delivered that evening. He always had a very clever way of avoiding those difficult problems and matters of controversy which could be so easily raised in connection with Trinidad. When he was first associated with that colony it was his good fortune to spend several months with Professor Cadman, and if they did not find oil at the time they certainly found some very high temperatures.

Following an expedition, he recalled that Mr. Cunningham Craig went into hospital with typhoid, and he (Mr. Thompson) was attacked by malaria, while Professor Cadman was the only one of the party who managed to escape. He did not think the real cause of the slow development of Trinidad had been mentioned. The real cause of the delay was, he thought, a more or less natural sequence of tropical operations, and was visible if the balance sheets of the various companies were studied. In going through a series of balance sheets of prospecting companies it would be found that the actual amount of money expended on drilling constituted a very small percentage of the total employed. He did not say that the directors or the experts were to blame for that.

There were numerous expenses which could neither be foreseen nor avoided in the initial development of an oil field, especially in a tropical climate. First of all, the health conditions had to be contended with; the managers went out and died, or had to be invalided home. A great amount of clearing and road making had to be undertaken, and as soon as good roads were built, floods came and did considerable damage, and when it was borne in mind that the roads in Trinidad cost £1,000 a mile, it would be easily appreciated how quickly a few thousand pounds of capital disappeared. Repeatedly roads had been made in Trinidad, and had been swept away afterwards by floods. If the actual cost of the wells in Trinidad was calculated from the balance sheets, it would be found that they had not really been very expensive. The most expensive wells had not cost more than 5,000*l*., while at a later date, through the employment of more modern machinery, many of the wells had not cost 1,000*l*. If companies working with a capital of, say, 50,000*l*. were able to spend the larger proportion of that money in actual drilling, the results would be quite different.

Another point to be borne in mind was that companies which prospected new countries could not evade the fascination of investing their money in new land. Companies which saw promising virgin territory on all sides could not be restrained from investing part of their funds in purchasing new lands, or at any rate undertaking obligations which entailed an outlay which was never provided for in the initial prospectus. Those points had a very much greater effect on the progress of a new industry than any other points that had been raised in the course of the discussion. He was quite sure that the first money spent in Trinidad by enterprising capitalists was well and honestly spent, but extreme difficulties had been encountered throughout. Staff troubles were universal; the native labour was difficult to handle at first, because it did not understand its duties; the imported labour left when they found the climate was not suitable, or because the bungalows were not so comfortable as they should have been, or because they had not the same food and pleasures as they had at home. Those difficulties threw on the management constant worry and expense, which was naturally reflected in the balance sheets. The development of Trinidad at the present day was, he considered, exceedingly satisfactory in the respect that the most serious initial difficulties had been overcome.

The drilling problem was at first a very difficult one; a well often took five or six months to complete, but it could now be

completed in 15 days. It was also important to bear in mind that the use of modern machinery enabled wells to be carried to deeper sources which naturally would be more prolific, so that a much larger volume of oil would be obtained per well than from the shallow wells. The modern methods of drilling which had been proved to be so satisfactory in most of the Trinidad oil fields enabled far less casing to be used, and everyone connected with the industry knew how fearfully expensive casing was, constituting often 50 to 60 % of the cost of the work.

Mr. Horace Wyatt said he felt he had no right to take any part in the discussion, because he knew nothing whatever about the industry in Trinidad. He simply rose for the purpose of endeavouring to obtain a little information referring to one small section of the lecture. Reference had been made to the fact that some of the wells in Trinidad gave an oil particularly rich in what was commonly known as petrol. He would be very glad to know whether there was reason to believe that such a quality of oil was obtainable in considerable quantities from the Trinidad oil fields, and whether the motor community might reasonably regard Trinidad with confidence as a future source of a large supply of petrol.

The second question he desired to ask related to the same interests, and dealt with the question of the difficulties of transport to which the lecturer had referred. He desired to know whether there was any field in Trinidad for the use of motor transport, either co-operatively or individually owned by the companies, or, conceivably, owned by the Government and hired to the companies which had purchased rights from them. Motor transport did not necessarily under such conditions mean the existence of good roads at all times, because there were certain forms of transport which could be operated where tracts were cleared, but where built roads were not in existence.

Mr. S. F. Stackard said it was a long, long way to Trinidad, and it also seemed an equally long distance between the petroleum and the sugar industry, but it might perhaps be of some interest to the members of the Institution to know that he had, during the last one or two years, shipped a considerable quantity of oil-burning plant to be used in connection and in conjunction with megass, which was sugar-cane refuse, for burning oil as fuel, and he was told by the users that fairly satisfactory results were being obtained from the plant. He desired also to associate himself with the remarks that had fallen from the President and other speakers in regard to Mr. Randolph Rust, whom he had the

pleasure of meeting a few years ago, and in regard to whose abundant energy it was almost impossible to do justice.

Professor Cadman, in reply, after thanking the members for the kind way in which his lecture had been received, said that although Mr. Cunningham Craig looked back upon his first report as the produce of his apprentice days, if read at the present moment from the point of view of the history of the subject, there was a great deal of value in it.

He was not going to be drawn into a discussion of the merits or demerits of an excise duty; it was not a question which came within the purview of the Institution, because a scientific institution of their character had nothing to do with politics.

He was very much obliged to Mr. Duckham for referring to the Darwent well. That was an omission on his part, and he thanked Mr. Duckham for calling his attention to it.

With regard to Mr. Wyatt's query as to Trinidad being a source of light oils, this was still an unsolved problem. The light oils came from the lower horizons, and there was a tract of country lying to the north of the central range which was still unexamined, and which he ventured to hope would make Trinidad one of the petrol-producing countries of the future. There was a good deal of motor transport going on in the island at the present time, and the roads in the colony were excellent, and as fine as in any British colony. The development of the roads dated back to the time of the active institution of a policy laid down by the late Director of Public Works, Mr. Wrightson, which policy had been amplified and continued by the present Director, Mr. Bell. His friend, Mr. McCarthy, whom he was glad to see present, had shared in the responsibility of this policy, because he was an active member of the Executive at the time the road scheme was introduced.

He had been much interested in the remark Mr. Stackard had made as to the use of oil in the sugar factories. Oil as a source of fuel was now being used in almost every industry in the colony. The use of coal, wood, and gas was gradually being superseded by the more economical and convenient local liquid fuel.

On the motion of the **President,** a hearty vote of thanks was accorded to Professor Cadman for his interesting lecture, and the **President,** having wished the members the compliments of the season, reminded them that the next meeting would be held on the 21st January, 1915.

Third General Meeting.

A Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Thursday Evening, 21st January, 1915, Sir Boverton Redwood, Bart., D.Sc., F.R.S.E., President, occupying the Chair.

The Members of Council present were: Prof. J. Cadman, Mr. Arthur W. Eastlake, and Dr. F. Mollwo Perkin. There was a good attendance of members and visitors. A letter of regret for absence was received from Sir Thomas Holland.

The President, in opening the Meeting, said that the author of the paper to be read, Mr. Cunningham Craig, needed no introduction to the members, and he would therefore at once call upon him to read the paper he had prepared.

The following paper was then read :—

The Prospective Oilfields of Western Canada.

By E. H. Cunningham Craig, B.A., F.G.S., *Member.*

In a short address given at a luncheon of the Royal Colonial Institute last year, I dealt with the prospecting work then being undertaken near Calgary, and gave some account of the extraordinary excitement that resulted from the first showing of light oil in what is known as the Dingman well.

To-night, my task is a much greater one, and I fear it can only be accomplished by dealing but briefly with each separate district or undertaking.

If the excitement in 1913 about petroleum was great, it was nothing to that which 1914 has seen in Western Canada, and not only Alberta, but British Columbia and Saskatchewan have been involved: prospecting for petroleum and even drilling has been attempted in so many districts, and under so many conditions of geological structure and environment, that merely to catalogue and classify them would require much time.

I propose, therefore, to treat these prospective oilfields, or localities where the optimistic prospector has hopes of discovering oilfields, from a geographical point of view, giving some account of each district where prospecting work or development work has been active.

But, before proceeding to a description of any field, it is necessary to give a brief résumé of the main geological data.

Practically all the petroleum that has been discovered in Western Canada has its origin in the Cretaceous formation, though it is possible that in some localities Tertiary strata will be found to be petroliferous. The Cretaceous formation varies very greatly in thickness in different parts of the country and has been sub-divided differently according to local variations in lithological characters, but it is possible, as a rule, to distinguish five main groups, three arenaceous and littoral and two argillaceous and marine or estuarine.

These groups are subject to great lateral variations, which make it difficult to attempt broad generalizations. There is a thinning-out of arenaceous sediment eastward towards Saskatchewan and Manitoba, accompanied by a great attenuation of the series. Again, from north to south there is a somewhat similar but less marked variation, which, however, is irregular, sandy and argillaceous groups alternately becoming predominant. Among the upper groups the variations are often very irregular and local.

The formation has been divided as follows:—

8. Edmonton Series ...	chiefly arenaceous, with lignite seams.
7. Bearpaw Shales	Estuarine and marine.
6. Belly River Group ...	Arenaceous, with coal seams.
5. Claggett Shale.....	A great shale group, the Cardium sandstone consisting of only a few thin bands of coarser sediment.
4. Cardium Sandstone...	
3. Benton Shales.....	
2. Dakota Beds	A mixed group with sandstones, shales and limestones.
1. Kootanie	Coal measures.

In other districts a different classification is necessary: thus on the Athabaska River the Dakota and Kootanie beds are apparently represented by a coarse arenaceous group—the well-known "Tar-Sands"—and these are succeeded by the Clearwater Shales.

Correlation with the series in Montana and Wyoming is fairly simple for districts near the American border, but becomes increasingly difficult as we proceed northward.

The Cretaceous formation is involved in the Rocky Mountains earth-movement, folding and contortion being intense in the mountains, less marked in the foothills, and then dying out rapidly as we reach the prairies. Thus folds of the lower members of the series, often defined by great overthrust faults, are characteristic of the mountain country, while the lowest beds are not as a rule exposed in the foothills, where the strata are over-folded, but more regularly and with less faulting. East of the foothills there is a broad syncline, followed to the eastward by an even broader but very gentle

anticline bringing up the Belly River beds, after which the formation is practically undisturbed.

The belt of greatest disturbance runs nearly north and south at the international boundary and for some distance to the north of it, but then gradually bends into a north-westerly direction, the intensity of the movement gradually decreasing at the same time.

Almost every part of the country thus roughly indicated has been prospected for petroleum; prairies, foothills, Rocky Mountains, synclines, anticlines, and monoclines, all have their share of attention during 1914.

It will be seen that of the various groups of strata in the Cretaceous formation, three are possibly oilbearing, the Edmonton series, the Belly River beds and the Dakota-Kootanie groups at the base. All these groups in one locality or another show signs of being petroliferous, but it is towards the lowest horizon that most attention has been directed.

The fields that have been prospected or tested can be subdivided into two groups, those where surface showings of oil are numerous and obvious, and those where it has been believed on theoretical grounds that petroleum may be found.

The Athabaska Field.—As already mentioned, the lower strata of the formation are known in the north of Alberta as the "Tar-Sands." These are oil sands of great thickness, which are well exposed on the Athabaska River from above Fort McMurray to below Fort McKay, and over thousands of square miles to east and west. The thickness exposed reaches as much as 200 ft., and seepages of heavy oil are very frequent along the river banks, while gas is in places evolved briskly from the bed of the river. The strata lie upon a very gently undulating surface of Devonian limestone. The river has cut a deep channel through an almost flat plateau, so that excellent sections can be studied, but on the plateau itself pine forest and muskeg occupy the surface so that it is only in stream sections that evidence is obtainable. The structure is almost absolutely horizontal, though some very broad and gentle undulations, and a few purely local disturbances hardly to be dignified by the name of anticlines, have been detected.

A number of wells have been drilled to test these conditions, but difficulties of transport and severe weather conditions in the winter have prevented continuous work from being carried on. Athabaska Oils, Ltd., have drilled five wells below Fort McKay, all of which have yielded oil from the Tar-Sands, through which, however, they pass at a depth of some 200 ft. The oil is heavy and sluggish in its flow, but gives remarkable results on distillation, sometimes containing as much as 60 % of light oils.

Gas-pressure is occasionally high, especially from beneath hard, close-grained bands in the Tar-Sands. The best results have been obtained from one of the small undulations, where a gentle arch permitted the accumulation of gas and oil under considerable pressure.

Timber for the derricks is cut on the spot, and plant is brought down the river on scows, which have to cross rapids, where there have been many accidents, and not a few cases of drowning. Road making through the forest and over muskeg is very difficult. Consequently there have been many delays in the development work, and though the first well was drilled several years ago, the field cannot be said to be in active operation yet.

Some wells have been drilled down into the Devonian formation for a distance of 800 or 900 ft., and have given very interesting results. Gas and light oils have been encountered in several porous bands beneath hard cappings, and salt-water occurs at more than one horizon. These lighter oils, however, do not occur in any great quantity, and are obviously filtered and derived from the younger oilrocks above.

Salt springs occur in many localities in the Devonian outcrop from which the Cretaceous strata have long been denuded.

The disadvantages of this field on the Athabaska River are obvious. The oilrocks are too much exposed, and structures of sufficient size to concentrate petroleum in quantity are wanting. At the same time wells can be very quickly and cheaply drilled, and if even a small steady production can be obtained from each, a commercial proposition will be in sight.

When the railway reaches Fort McMurray and Fort McKay, the great difficulties and expenses of transport will be things of the past, and this field may be actively worked, but it is probable that it will be found more profitable to dig out the tar-sands with steam shovels, and extract the oil by means of one of the new low-temperature processes, such as the Del Monte, by which yields up to 30 gal. per ton can be obtained.

West of the Athabaska River there is a vast area over which much the same conditions prevail. The strata lie horizontally, and though some gentle undulations have been proved by levelling, it is doubtful if they are sufficiently well-marked to have had much effect in concentrating petroleum.

It is only in river sections that good evidence can be obtained, and the Wabiskaw, Peace and Smoky Rivers enable the general features of the geology to be ascertained. In some localities the tar-sands are covered by a fairly thick mass of newer sediments, and it is possible that fair productions might be obtained.

Going northward and north-westward the strata are more extensively denuded and tar-sand outcrops are frequent, while beyond vast plateaux of Devonian strata appear, often containing along joint-planes and in porous beds the remnants of a former impregnation with petroleum. It is doubtless such occurrences that have supported the idea that the Devonian formation is the source of the petroleum in Western Canada.

In some cases fairly light filtered oils are seen exuding from limestone outcrops, and samples of such oils have been brought back by trappers and explorers. Much prospecting work has been done in this region, particularly on the Peace River, and Dr. Bosworth has recently made traverses over a very wide area, but the necessity of keeping to rivers and watercourses has militated against a complete geological examination of the country.

So far no very promising areas have been marked out, and till the region is opened up by railways and roads it is not likely that any development work on a large scale will be attempted.

The Flathead and Pincher Creek Fields.

The next area in which the lower groups of the Cretaceous formation are seen at the surface to be petroliferous is near the International Boundary. On the Flathead River in British Columbia, especially on its tributary Sage Creek, seepages of light oil are observed, and two or three shallow wells have been drilled and have encountered oil not far from the surface. The geological structure in this case is very different from what we have been considering in the northern areas. Earth-movement has been intense, the area being actually within the Rocky Mountains, and the Devonian Limestone is actually brought above outcrops of Dakota and Kootanie strata on great overthrust faults. It has yet to be proved that commercial production can be obtained in such circumstances, and geologists do not hold out great hopes of a paying oilfield being proved, but the point of importance is that it is possible to drill through outcrops of the Devonian strata into the lower zones of the Cretaceous, and find them oilbearing.

On Pincher Creek in Alberta, not far to the eastward, "shows" of oil have been known for many years, and the Lineham well caused quite a boom in the Pincher Creek district some years ago. Most of the drilling, however, was quite unsuccessful, and though the Lineham well has again been opened, and is producing an oil of about 40° Baumé gravity, the geological conditions do not seem sufficiently favourable to admit of a large or profitable field being

possible. Active development work, however, is again in progress, and new discoveries in this region may be forthcoming in the next few months.

The Calgary Field.

The fields described above furnished valuable evidence pointing to the possibility of an oilfield being discovered in the eastern foothills of the Rocky Mountains, where the lower zones of the Cretaceous formation do not crop out, but where a series of well-defined anticlines has been mapped or delineated. This we may call the Calgary Field, which has seen such extraordinary excitement and activity in 1914, though many of the districts exploited are very far from Calgary.

Beyond a few bituminous stains and oozings, there are no actual seepages of oil in this foothill country from the latitude of Edmonton to that of Lethbridge, but natural gas-wells are not uncommon, and the gas is obviously a heavy or "wet" gas. Samples of water with a film and a very strong odour of light petroleum have also been brought to me from several localities.

Several geologists and prospectors had examined large areas in the foothills with a view to discovering oilfields, but active development only began in the late autumn of 1912 when the MacDougal-Segur Syndicate and the Calgary Petroleum Products Co. began drilling on the same anticline some 35 miles from Calgary.

In the autumn of 1913 the first well of the latter company, which was located near a large gas-spring, struck a remarkably light oil, in small quantity, at a depth of 1562 ft. Very strong gas had been struck at more than one horizon before, and with the first signs of oil the excitement now known as the Calgary Oil-Boom began.

The oil was extraordinarily light, containing from 70% to 80% of petrol, and a foolish rumour was at one time current that the well was salted. The show was a small one, and drilling was soon continued, while many other companies were formed to develop neighbouring areas, or areas selected geologically as appearing of promise. In May of last year, at 2718 ft., the well struck oil of practically the same grade, but in much larger quantity, and the oil-boom, which had languished, burst out afresh with renewed strength and unprecedented audacity.

I had visited the well five days before the strike, and had satisfied myself that a strike of some kind was imminent, and I visited it again the day after the oil was reached. At that time I judged that the well was capable of producing from 15 to 25 barrels per

day, but subsequent history has shown that an average production of about 10 barrels is nearer the truth. The oil is accompanied by very strong gas.

The quality of the oil is remarkable. A specimen I sent to London analysed as follows :—

Specific gravity	0·729.	
Benzine	72 %.	Sp. gr. 0·714.
Kerosene	20·2 %.	„ „ 0·793.
Solid Paraffin	2·5 %.	
Loss	5·3 %.	

Fresher samples give even more remarkable results.

It seems quite evident that this oil, which is almost water-clear, is a filtered product, or is naturally distilled from some other source and condensed. Used crude on a motor car, it gives astonishing results; in a car which I used frequently this crude oil took us on high gear up a hill that the car had never been able to negotiate on high gear before.

It is unnecessary to give any account of the boom which followed this discovery of oil, but it is very difficult to speak of the Calgary field without condemning something like three-quarters of the development work that has been, and is being, done. Yet it is not fair to the few companies that have proceeded on careful and scientific lines to class them with the crop of mushroom speculative ventures that were soon in operation.

It is more important to deal with the geological conditions, which are sufficiently puzzling in themselves.

Many geologists have visited this prospective field, and some have spent many months in detailed study of the strata and structure, but several points still remain obscure, and several very incorrect sections have been published. I must plead guilty to having had an incorrect idea of the initial horizon of the Discovery Well.

According to the Geological Survey maps, the well has its initial horizon in the Bearpaw Shales, and in that case, owing to the position of the well to the eastward of a sharp anticlinal crest it can hardly have pierced beyond the Belly River Beds at a depth of 2718 ft.

But in the last few months some interesting new palæontological evidence has been brought to light. This evidence has been studied by an acknowledged authority, Dr. J. P. Smith, of Leland Stanford University, and though I am not in a position to give full details, the main conclusion is that what were taken for Bearpaw Shales on the west of the Turner Valley Anticline are really of Benton age.

This means that the gas and light oil struck in the well must have its origin in the Kootanie Beds, and that much of the mapping of the Geological Survey will require to be revised.

This result is very interesting, as on other anticlines further to the westward several wells are being drilled, beginning low down in the Benton Shales, in the expectation of finding the Kootanie Beds in the petroliferous phase.

With regard to wells drilled on the same anticline as the Discovery, or as it is called, the Dingman Well, there is little to be said. Some are situated too far east, and some too far west, to have good prospects, and none have yet reached the necessary depth. All have encountered gas in greater or less quantity, and one, the second well of the Calgary Petroleum Products Co., has tapped a very strong flow of gas, estimated at anything up to 2,000,000 cub. ft. per day. One well has had a showing of brown oil at about 2200 ft.

The future of this part of the field is still in doubt. There have been many criticisms levelled at it by persons either ill-informed or "wise after the event," and the Dingman Well has been only too often spoken of as a "freak," a frank admission that it is not yet understood. But the carefully considered opinion of geologists is to look upon the heavy gas and light oil as evidence that a body of heavier oil exists somewhere in the neighbourhood, and has yet to be discovered. In cases such as this, where many parts of the ground are obscured by drift, and where faulting undoubtedly exists, though not to such an extent as many would have us believe, the wisest course is not to hasten to bless or condemn the field, but to wait patiently for each new piece of authentic information that is brought to light.

With regard to anticlines lying further to the west, a good deal of detailed work has been done, and there is still considerable difference of opinion. Three or four companies are drilling on such flexures, and some encouraging indications have been met with, but, up till the present, results have been distinctly disappointing. The strata are of the same age as those so well developed in Alaska north and south of Behring Lake, to the south of which, at a little place called Redwood (after our President), some half-dozen wells have been drilled, and all have struck oil of very good quality, though not in great quantity at comparatively shallow depths. The interesting point is that north of Lake Behring the same strata are coal-bearing, and indeed contain important coalfields. The theory upon which these western anticlines are being tested is that the hydrocarbon contents of the Kootanie Beds would be found where sealed up by

the great mass of the Claggett-Benton Shales and Dakota Beds in the form of petroleum. The chief criticisms that have been put forward against the probable success of these speculative wells are, firstly, that the strata are too much broken up by faults and disturbances, and, secondly, that the strata do not contain water.

The structures certainly are complicated and minor faulting is present, but in the areas I have had most to do with faulting is not nearly so prevalent as has been represented, and the thick mass of impervious strata pierced is certainly sufficient to seal up any oil that may be present at greater depths.

As for water, the strata drilled through are too impervious to contain it, except at rare intervals.

The only two conditions that can militate seriously against success are, first, that the hydrocarbon contents of the Kootanie measures may have died out eastward, or, secondly, that the lignitic or coal-bearing phase may have been reached in these strata before they have been sufficiently deeply buried by later sediments. A conglomerate at the base of the Dakota rocks, probably representing a slight unconformability, certainly suggests the probability of the latter adverse condition.

An unforeseen thickening out of the Dakota beds eastward has caused drilling to be much deeper than had been anticipated, but slight shows of oil and gas have been encountered through hundreds of feet of the Dakota formation in wells of both the United Oils of Alberta, and the British Alberta Oil Co. This certainly suggests that the oil-bearing stage has been reached, and had any really porous stratum been pierced I have little doubt that it would have contained oil.

Quite recently I have learnt that the first well of the United Oils of Alberta, situated on a small anticline three miles westward of the Dingman Well has entered the Kootanie Beds, found them in the carbonaceous phase, and the well has been abandoned, perhaps somewhat inadvisably, without making a thorough test of the formation. Various rumours as to the reason for this abandonment are current, but one thing seems certain, viz. that the geologist who located the well, Mr. J. H. Sinclair, is dissatisfied.

Another recent occurrence in the field is of interest. The Moose Mountain Oil Co., drilling a well which I had the pleasure of locating some 20 miles further to the north, has had a very good showing of oil at a depth of about 1600 ft. This oil occurs in the Dakota Strata: it is dark brown in colour, with a green fluorescence and is of paraffin base and very good quality.

A sample analysed by Mr. Edward G. Voss, gives the following results :

Sp. Gr. 0·824 (40° Baumé).

Distillate	below 100° C	7·2%	Sp.Gr. 0·693	Light Benzines	20·6
,,	100° C – 150° C	13·3%	,, 0·746		
,,	150° C – 200° C	8·0%	,, 0·783	Illuminating Oils	34·8
,,	200° C – 250° C	11·8%	,, 0·811		
,,	250° C – 300° C	15·0%	,, 0·839		
,,	300° C – 350° C	27·0%	,, 0·847	Lubricating Oils	37·0
,,	350° C – 370° C	10·0%	,, 0·877		

Residue, pitch about 5 %.

This is an oil of high grade, and should give good profits on distillation, if it can be obtained in sufficient quantity. The point to be noted is that such an oil appears very like a parent oil, from which such a filtered product as that struck in the Dingman Well might be derived.

It seems possible that faulting may have had adverse effects near the Sheep Creek field, especially as we know that faulting increases from there southward, more particularly where gas is frequent, and that further north more favourable conditions may be present.

Besides these western anticlines, there are others that are being tested in the Calgary field, both to north and south. On some of these much higher horizons are exposed. The Monarch Oil Company is drilling about 70 miles north of Calgary, beginning in the Edmonton series. This well has had several good shows of wet gas and oil, but has been carried down to 3500 ft. without obtaining production.

The anticline has been traced south-southeastward to the south of the Bow River, which it crosses at Mitford. Several companies are testing it south of the Bow River, e.g. the Dome Oil Co. and the Purity Oil Co. The latter has had a show of heavy oil at shallow depth (900 ft.), and both have encountered gas. Much drilling will have to be done before we can have any certain knowledge as to the prospects of exploitation among these higher horizons.

Further to the northward near Rocky Mountains House two anticlines have been mapped, and one at least is now being tested, the well beginning in the Edmonton strata. These folds, or very similar parallel ones, appear again on the McLeod and Athabaska Rivers west of Edmonton, and though the strata exposed are high in the series, conditions seem very favourable for a test, especially as coal for fuel, water, and railway transport are all available and on the spot.

A great area is still very little known and difficult to examine on account of glacial drift and pine forest, but in these northern extensions of the Calgary field earth-movement has not been so severe, and geological structures are certainly favourable for oil formation. Time, however, will not permit of a detailed description of those areas I have examined.

Vancouver Area.

In British Columbia, near Vancouver, there has been some prospecting, and much land has been taken up for exploitation. There is a small seepage of light paraffin oil from a Tertiary outcrop in the woods of North Vancouver, but the ground is very obscure, and the structure, so far as I could ascertain, is a gentle monocline.

Folds are believed to exist both in Tertiary and Cretaceous rocks south of the Fraser River, but alluvium and glacial deposits mask so much of the ground that any drilling that may be undertaken can only be very speculative.

Just across the international boundary in this neighbourhood gas has been struck in shallow water-wells, but the only well drilled for oil is apparently in a synclinal area, and so far has been quite unsuccessful. Yet it is possible that a field may be opened up in this direction.

It has been impossible to give any account of many interesting occurrences, seepages, gas-shows, &c., that I have examined, and I have purposely left out all allusion to wild-cat wells drilled on the prairie. Forty-three wells were drilling recently, and though a few have been abandoned, others have probably been commenced. It is regrettable that so many ventures have been started when a comparatively few careful tests would be sufficient, but that is one of the unfortunate consequences of an oil-boom.

The excitement in Calgary has by now died down, as it has been realised that deep and expensive drilling is necessary, and there are pessimists who do not hesitate to condemn all Western Canadian fields indiscriminately. Such an attitude is to be deprecated till more conclusive data are available. All drilling for oil is to some extent speculative, and no one who has studied these western prospective fields with any care has failed to point out over and over again that, though the rewards of success would be great, the possibility of complete failure in any one district is considerable. Yet when we consider the vast extent and numberless variations of the Cretaceous formation, the many different structural conditions, and the fact that almost everywhere indications of petroleum of some kind, either as gas-wells, oil-seepages, outcrops of bituminous

strata or showings in drilled wells are recorded, it seems almost impossible that there cannot be a paying oilfield waiting for development somewhere between the far north and the international boundary. It may be in the Tar-Sand country, it may be among the gentle domes of the prairie territory, the Sweet Grass country, or the much criticised Calgary field, or one of its unexplored northern extensions. There will doubtless be many disappointments, for much of the development work now in progress was predoomed to failure, but I believe, and I think that everyone who has travelled sufficiently in Western Canada will concur, that there is petroleum in these great territories, and that it will be discovered and produced profitably at no very distant date.

DISCUSSION.

The President said the most remarkable feature in the vast area which had been dealt with in the paper was unquestionably the deposit known as the Tar-Sands, and it was not surprising that the existence of such an immense quantity of inspissated or evaporated petroleum should have led to the belief that there must be somewhere in the region an available oilfield, although it was, of course, open to objectors to say that as so much oil had come out, it was not reasonable to expect that much oil remained to be found.

Some idea of the enormous quantity of petroleum represented by that mass of sandstone saturated with asphaltic petroleum residuum could be gathered from the figures that were put forward by some enthusiastic arithmetician some years ago, who laboriously calculated that the Tar-Sands actually contained no less than 6½ cubic miles of bitumen. He did not think the gentleman to whom he had referred went to the length of further endeavouring to calculate how much crude petroleum that 6½ miles of semi-solid bitumen represented.

He believed the first attempt to find oil in the region dealt with in the Paper was made by the Dominion Government somewhere about the year 1894. Further attempts were made in 1897, but, for various reasons, none of those efforts produced any hopeful results. It would obviously be of the greatest importance at the present time if an oilfield of a productive character could be developed in that part of the world, because it was well known that the petroleum industry of Canada, which had its birth in 1861, within a year or two of the commencement of the petroleum industry in the United States, and which, when he first visited London,

Ontario, about thirty-five years ago, was a flourishing industry, had within the past few years been conducted under great difficulties and great discouragement, and bid fair in point of fact soon to be an industry no more.

Obviously it would gladden the hearts of motorists if they were able to find in that region a crude petroleum, such as that referred to by the author, which they could use in their motor cars as it came from the well, even though the odour might not be agreeable. He therefore shared the hope which the author had expressed that the work which was being done--much of which no doubt had been injudiciously conducted, but part of which had been at any rate productive of a certain amount of useful knowledge—might ultimately result in the establishment of a profitable industry.

There were present at the meeting many gentlemen who were interested in Canada, some at least of whom were acquainted with the region dealt with in the Paper. One of them had been referred to specially by the lecturer as having carried out extensive investigations in that area—Dr. Bosworth—and he was sure the members would be very glad to hear what he had to say, even though it should be found, as was often the case when two men engaged in the same profession were dealing with a problem presenting considerable difficulties, that Dr. Bosworth did not entirely concur in some of the views which the author had expressed.

Dr. T. O. Bosworth said it had been a great pleasure to him to listen to Mr. Craig's interesting Paper, and to hear his views on the Calgary oilfield. There were several points on which he desired to comment, as he had spent practically the whole of the year 1914 in Western Canada. With the help of several assistant geologists, his explorations had been pursued over a very great region, of which the Calgary oilfield was but a very small part. The Calgary field was examined by him in February and March; again when oil was struck, and again last December, and he regretted to say that he had never been able to form any favourable opinion of the prospects there.

The chief point against that field, in his opinion, was the lack of indications of oil. The Cretaceous system was extensively exposed under all sorts of conditions, e.g., the rocks were sometimes vertical, sometimes there were arches, sometimes there were overfolds; sometimes the beds dipped gently. It was possible to follow the Dakota and Kootanie outcrops for many miles, and surely, if those formations had been petroliferous, abundant seepages would have been found on the foothills of the Rocky Mountains.

It was true that there were some seepages of gas, notably four.

Southern Alberta had already been proved to have a large gas field, 150 miles east of the foothills, but no oil whatever had been discovered in any of the gas-wells. Fifty wells had already been drilled in the Calgary region, three of which had depths of between 3000 ft. and 4000 ft., and many of them depths of from 2000 ft. to 3000 ft. A number of those wells had been located with the greatest skill by such distinguished geologists as the lecturer, and yet the results had not been obtained that had been expected.

The public of Calgary and business men deserved the greatest credit for the energy and enterprise they had shown in their endeavour to get oil, but the fact remained that millions of dollars had been spent in that district, and the result, up to the present time, could be called nothing more or less than a failure.

On account of the views he held, but having at the same time a great wish to find oil in Western Canada, he turned his attention to the North country, and spent the greater part of the year in traversing those great regions, and making investigations there.

The author had kindly made mention of his (Dr. Bosworth's) activities, for which he thanked him, but he wished to take exception to some of the remarks he had made about the North country; in fact, some of them he wished emphatically to controvert.

In his opinion the discoveries which had been made in that region were of the greatest importance. Fields of the utmost promise had been marked out, bearing all the indications and evidences that any unexploited field could be expected to show; evidences, in fact, which the Calgary field did not show. The degree of importance of those finds must remain to be estimated at a later date, as the present was not the time to deal with them; he thought they were worthy of being mentioned on a special occasion. In his opinion, the failure at Calgary need not dishearten the Calgary men nor any others who had made up their minds to find oil in Western Canada. The Calgary boom was but a preliminary incident in the real development which must some day follow in Western Canada.

He desired, in the next place, to call attention to the distances in the country to which he was referring. Travelling northward from the United States boundary to the Arctic Ocean, there was a distance of 150 miles from the boundary to Calgary; 200 miles from Calgary to Edmonton; and from Edmonton to Athabaska Landing, the end of the railroad, another 100 miles, i.e. 450 miles altogether to the end of the railroad. From Athabaska Landing to the Arctic Ocean was another 1400 miles, and it was right through that great region that he and his assistant geologists had travelled during the past summer in search of oil.

The author had said a good deal about the Tar-Sands, and a little about the North country, but from the views that he had expressed it was evident he had never visited the Tar-Sand country himself, although he believed that he sent a geologist there to investigate the Tar-Sands. If Mr. Craig had personally inspected them, he would not have said what he had in regard to them.

The speaker did not think it opportune as yet to deal with the results of his investigations there, but he thought it would be of interest if he narrated some of the bare facts that had been observed.

The Tar-Sand formed cliffs of sandstone over 200 ft. high, saturated with oil, and resting unconformably on a floor of Devonian limestone, being exposed for nearly 100 miles along the Athabaska valley. He thought the evidence of the Tar-Sand was very satisfactory, and he did not think any shales had been found in it.

The rock was almost wholly black and plastic, although it weathered to a greyish colour in the cliffs. The great sheet evidently extended over something like 2000 square miles, and very probably over 10,000 square miles. From experiments which he had personally made it gave, on distillation, a yield of about 14 gal. of oil per ton, a considerable proportion being gasolene.

He did not think it could be doubted that the exposure of Tar-Sand in that region was the greatest exposure of pitch, tar and crude oil in the whole world, and greater than that of all the rest of the world put together. The contents, presuming the whole distance produced the same amount as in the part examined, would amount to 200,000,000,000 tons of oil, which would be sufficient to last the world, at its present rate of consumption, for about 2000 years.

About 15 wells had been drilled there in the Devonian rocks under the Tar-Sand, and five in the Tar-Sand, and towards the end of the year one or two other wells had been drilled. Those drilled in the Tar-Sand had yielded black oil, too viscous to be pumped, and giving on distillation 5 % gasolene, 60 % kerosene, 15 % lubricating oil and 20 % of coke. The present was not the time to proffer conclusions as to the nature, source and mode of accumulation of that field, but, in his opinion, the proper exploitation of that Tar-Sand had not yet commenced.

He was entirely at variance with the views held by the author in regard to the Devonian formation. Even if Mr. Craig had seen the Tar-Sand region, he would not be justified in forming an opinion about the Devonian formation, as only about 50 or 100 feet, at

most, of the Devonian was exposed in that region. The statements the author had made gave rise to the impression that the Devonian was an unpetroliferous formation, and that any oil found in it had been derived from Cretaceous or Tertiary rocks overlying it. Both those statements were, in his opinion, erroneous.

It was true that in the Tar-Sand region bituminous matter had descended into the crevices in the Devonian limestone, but he believed that the oil in those Tar-Sands had been derived from the Devonian somewhere else. The Devonian was a great petroliferous formation. Its various sub-divisions, or at any rate a large part of them, had been worked out by him during the past summer. It was not at all like what the author supposed, and in some parts there were systems of folding and mountain-building anticlines.

He could, at the present moment, call attention only to the following facts. The source of the oil in the Devonian formation was a thick black shale, several hundred feet thick, and much black bituminous limestone. From the shales oil could be distilled, and it was pretty obvious that the oil had been derived from them, and passed into overlying porous rocks, sandstones and dolomites, in the Devonian formation. The black shales covered a wide extent of an enormous area, and in some places they were actually undergoing combustion at the present time. In several places oil was seeping out from the Devonian rocks into the water for distances of several miles. In other places there were large deposits of asphaltum far into the Devonian district. Yet again there were numerous pools of oil among the Devonian rocks, which could be baled out with buckets.

His findings on the whole confirmed the opinion of Mr. McConnell of the Canadian Geological Survey, who went through the region in 1888, and there was no doubt at all that the Devonian was a petroliferous formation.

It was not wise to promise too much in regard to an untested region, but he thought it was safe to say that in the Devonian formations in the north they were dealing with a petroliferous region, that the oil was generated truly in the Devonian rocks, and that in that region all the geological evidences of oil conspicuously occurred.

Professor John Cadman said it was always a pleasure to hear two specialists discuss a problem, because they invariably dealt with it from different points of view, and, in the end, they always found that two distinct propositions had been confounded. There might be some people present who did not really understand the geologists as he ventured to think he did. Although Mr. Craig and Dr. Bosworth

had expressed opposing views, they had done so on really separate geological questions, each bringing forward facts but slightly connected with the other's arguments.

It was his pleasure some years ago to go over part of the area which had been discussed by the lecturer at a period prior to any drilling for oil; and from information that had been published since, and from his own researches on work that had been done on the subject, he felt that the area to which Mr. Craig had referred was one which was worthy of test, always on the assumption that people were prepared to accept the vegetable origin of petroleum.

On the one hand, there were great carbonaceous tracts with coal-seams outcropping on the flanks of the rocks; on the other hand, at approximately the same geological horizon at some small distance away, compared with the great country to which Dr. Bosworth had referred, there were the great deposits of Athabaska Tar-Sand.

On the one hand, there was coal and, on the other hand, there was tar, asphaltic residue, both part and parcel of the same original vegetation; and one then began to look for a structure in which it was suitable to find conservation or storage of that valuable liquid.

The geologist located the various anticlines or flexures, and the engineer then came forward, and tried to get a hole down to the horizon which, in the particular region referred to by the author, was, he understood, known as the Kootanie series, an endeavour being made to pierce that particular series. Although he considered the problem an extremely speculative one, he thought it justified a test.

As far as he was aware, although some 58,400 odd feet had been drilled by the 43 or 50 wells which had been referred to, no evidence as to the conditions of the Kootanie formation in that particular locality had yet been forthcoming. Personally, he was sceptical on the point. He was not prepared to support either view until he knew whether the Kootanie formation had coal seams in it or oil sand.

There were many of the members who looked with considerable interest upon the work of the lecturer and of Dr. Bosworth. Pioneer geologists were always to be congratulated on their arduous tasks in countries of the nature to which the Paper referred, and he congratulated the Institution on having heard a Paper of a most interesting character which had produced a very animated, interesting and instructive discussion.

Mr. E. H. Cunningham Craig, in reply, thanked the members for the very kind way in which his Paper had been received, although he admitted it did not do anything like justice to the great

subject which he had attempted to put before them. He did not refer to the Government work on the Athabaska River, because he feared if he went into those details he would occupy far too much time. He desired to inform the members that the well drilled at the Pelican Rapids was still flowing gas at a fairly rapid rate, in spite of the many years it had been active.

Dr. Bosworth had mentioned that he had never had a favourable opinion of the field to which the Paper referred. Personally, he would have been very glad if he had heard Dr. Bosworth's opinions on the matter before, and his reasons for them, because he did not think it at all followed that, because there were no seepages of oil in the outcrops to the westward, i.e. the outcrops of the Dakota and the Kootanie formations, it was impossible to find those rocks in a petroliferous state when they were struck well sealed up in an anticline.

If Dr. Bosworth had spent more time in the study of the foot-hill fields, he would have found there were a certain number of indications of oil, not in the way of seepages, but in the way of veins of ozokerite, and in slight bituminous oozings, which he had seen in several places. In addition he had brought to him from several places specimens of water with a film and a very strong odour of light petroleum, very much of the nature of the Dingman oil. So that although it could hardly be said that seepages of oil and surface indications of oil were frequent, there certainly were some in the foot-hill country, especially up northward from Calgary.

Dr. Bosworth also stated that no oil had been found in gas wells in the prairie Provinces.

The Gas Companies certainly did not admit that any oil had been found, but he knew that in at least one well a certain amount of oil had been found, and he believed that wells were going to be drilled shortly in gentle domes in that prairie country in the hopes of finding oil, the idea being that the gas wells had not penetrated far enough into the Dakota formation, and that the Kootanie formation would be found below, and might prove to be petroliferous.

With regard to the northern fields which Dr. Bosworth had prospected, he believed there might be—and he thought he said so in his Paper—very good prospects in many places, but until some arrangements were made for transport (and it would be many years before the country was properly opened up by railways) it was almost absurd to talk of prospecting those territories with the drill.

He could confirm Dr. Bosworth's statement that 14 gal. per ton, and frequently very much more than that quantity, could be obtained from the distillation of the Tar-Sands. He thought

Dr. Bosworth and himself had better agree to differ on the question of the Devonian series. If Dr. Bosworth had seen some of the evidence that he (Mr. Cunningham Craig) had seen in other countries of how very deep impregnation downwards might go from a petroliferous series; how the oil was removed after the denudation of that petroliferous series from the more porous beds, and was only found in those that were less porous, for instance, in the shales, he might have hesitated in claiming the Devonian of Western Canada as a petroliferous formation, especially as the Devonian was so well exposed over such a great part of the Rocky Mountains.

Those who had been in Western Canada had, he was sure, thoroughly studied that point, and that formation certainly did not appear to be highly petroliferous.

He had very little to say in answer to Professor Cadman, except to admire the way in which he dealt with controversial matters in geology. It was a great gift, for the possession of which he envied Professor Cadman.

The President said the happily phrased and eloquent speech of his friend Professor Cadman had dealt so effectively with the points of difference that had been alluded to between the lecturer and Dr. Bosworth, that there was not very much for him to say on that particular aspect of the matter, but it occurred to him there was one way in which Dr. Bosworth could serve the interests of the Institution and, incidentally, afford himself the opportunity of dealing more fully with the subject, namely, by giving the Institution a Paper on the northern region to which he referred, especially an account of the Tar-Sands to which he had devoted so much attention.

He was quite sure the Honorary Secretary would be very glad, before Dr. Bosworth left the building, to discuss with him the question of the first available date for a Paper of that kind; and on behalf of those present he ventured to express the hope that the interview would be of a satisfactory character.

It only remained for him, on behalf of the members, to propose a very hearty vote of thanks to the lecturer for his interesting and valuable Paper.

The Resolution of Thanks was then put and carried with acclamation.

Fourth General Meeting.

A Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C., on Thursday Evening, 18th February, 1915, Sir Boverton Redwood, Bart., D.Sc., F.R.S.E. (President), occupying the Chair.

The Members of the Council present were Professor John Cadman, Mr. Arthur W. Eastlake, Sir Thomas H. Holland, K.C.I.E., Professor Vivian B. Lewes, Mr. T. C. Palmer, Dr. F. Mollwo Perkin, and Mr. Robert Redwood. The attendance of members and visitors was about 130 in number.

The Hon. Secretary (Mr. Arthur W. Eastlake) said he had the honour to inform the members that Admiral of the Fleet Lord Fisher of Kilverstone, and Vice-Admiral Sir Edmond J. W. Slade, had accepted the invitation to become Honorary Members of the Institution.

The following gentlemen had been elected as:—

Members:—Andrew Campbell, John Edward Marshall Hall (transference from Associate Membership), Francis Augustus Holiday (from Associate Membership), Mathew Lodge, Thomas Samuel Masterson, Arnold Philip, George Bernard Reynolds, Ivan Ascanio Stigand (from Associate Membership), and Norman Sutherland. As *Associate Members*:—Francis Douglas Brown, Charles Erik Capito, and Ernest Edward Rigold.

He had also to announce, in compliance with Clause 23 of the Articles of Association, that the Council proposed the subjoined slight modifications of the By-Laws:—

1.—That Clause 5, Section vii, be amended to read as follows:—

At least thirty days before the date of the Annual General Meeting the Council shall, in the event of there being more than four members for re-election or nominated for election to the Council as hereinafter provided, prepare and issue to each Member and Associate Member having a registered address in the United Kingdom a list of Members for re-election and nominated for election to fill the vacancies caused by the retirement of Members of Council, such list to be regarded as the Balloting List. Every Member and Associate Member of the Institution may submit in writing to the Council the name or names of Members whom he desires to recommend for Council, but such nomination must be delivered to the Secretary not later than the Fifteenth day of November in any year, and the Council shall decide by ballot upon the inclusion thereof or otherwise in the Balloting List. Each Member and Associate Member balloting is entitled to erase any name or names from the Balloting List, but any Ballot List shall be deemed invalid if the number of names remaining thereon shall exceed the number required to be elected. (Remainder of Clause to stand unaltered.)

2.—That Clause 11, Section vii, be altered to read:—
Additional Members of Council may be appointed, or casual vacancies on Committees may be filled, by the Council.

3.—That Clause 3, Section ix, be altered by adding "if any" after the words, "the result of the ballot," in the third line.

The alterations, of which the members would receive notice in due course, would be considered and voted upon at the Annual General Meeting to be held on March 24th, 1915.

The President announced that, in addition to the paper of which notice had been given in the invitation cards for the meeting, a paper would be read by Prof. Vivian B. Lewes, of which most of those present had received a copy. The author of the first paper, Mr. William A. Hall, who might not be known to all the members, was a research chemist who had been conspicuously successful in solving several very important industrial problems. Both papers dealt with a subject which of late had attracted a large amount of attention, namely, the conversion of heavy oils into petrol and certain other products.

The following paper was then read:—

The "Cracking" of Oils with a view to obtaining Motor Spirit and other Products.

By William A. Hall, *Member*.

I have been asked by your most able Chairman to read a paper on the cracking of oils.

I appreciate that this is a very difficult subject, one on which there is a wide divergence of opinion. I expect that my article will evoke criticism, and that many experimenters will differ with me—that their observations will not coincide with mine. This, however, is most natural in dealing with such a complex reaction, if reaction it may be called, where slight variations of time, temperature, pressure, speed of flow and their various combinations make wide divergence in the results, and when different styles of apparatus create unexpected, and in some cases, unexplained changes of the greatest moment: also, where different characters of oils worked under the same conditions, give entirely different yields and character of product. I propose to give you simply the results of my own observations, not attempting to consider or explain the totally different results that may have been obtained or published by others.

I intend also to give you principally the results obtained in large apparatus of full commercial size, which may differ greatly from those obtained in smaller or laboratory apparatus. Perhaps, one reason why the art has not more rapidly progressed is the practical impossibility of conducting experiments to any definite degree in the laboratory, and the expense of its conduct on the smallest scale of commercial value has proved very considerable, sufficient to deter much extensive research. Of course, there are underlying principles governing the operation, but they do not appear to be very generally understood.

The ability, by cracking, to produce low-boiling fractions from oils of high-boiling points, accompanied to some extent by a considerable decrease in gravity, has been well known for many years. But cracking to produce or increase the yield of lamp oils is a very different matter from the production of paying quantities of good quality motor spirit from heavy distillates, and in consequence of the low price and small demand for petrol, there was until recent years no incentive to improvement of procedure. Your honourable Chairman was at least one of the fathers of the process, as is clearly shown in the well-known patent to Dewar and Redwood of 1890. It is most interesting to note that this very invention of condensing under a considerable pressure has quite recently been revamped in the so-called Burton process, now so largely practised by the Standard Oil Co. in America. I am informed that they are operating at present several hundred 200-barrel stills in the conduct of that process, and that this output has had a most material effect both in the volume and price of petrol, though you, who are motor-car owners, would scarcely realise it, when you purchase petrol by retail in Great Britain at from 1*s.* 6*d.* to 1*s.* 9*d.* per gal. On the subject of the Burton process and the quality of its product, I may have more to say. It suffices now to call your attention to the very considerable additions to the supply that these several hundred large stills must create, and their number is being rapidly augmented. From this alone I think we can realise how important a feature cracking is likely to be in the future. The art is only in its infancy, and very great improvements are sure to be forthcoming.

But it is very significant that the very greatest company producing oil and motor spirit has taken up cracking so extensively, and it was only about two years ago that they started it on a really commercial scale with a few small stills at Whiting, Indiana. To increase to this enormous extent in so short a space of time, shows the importance that *they* attach to the subject, and this notwith-

standing that they admit that their process leaves much to be desired. In fact, from all that I can learn, it produces a spirit that does not give satisfaction if used alone, but requires a very considerable addition of high-quality petrol. But even if an addition of as much as 50 % of good petrol was required, it would still be a most important factor in the supply, whilst if a conversion of but 30 to 40 % was obtained from such distillates as they can utilise, it would mean substantially doubling the output from a given oil. What this means for the future you can readily realise. It is (economy aside) as if new wells were developed of double the petrol constituent in the oil, and almost unlimited in extent. That the Standard Oil Co. are satisfied with the economy of the operation is clearly shown by their enormous extension of plant.

Though cracking is undoubtedly in its infancy, it is now on the sure road for rapid extension, and must play a most important part in the future and in many countries.

Especially is this the case where, as in the majority of the newly-developed fields, the oil is deficient in low-boiling fractions, and the petrol production derived from such oils could never keep pace with the ever-increasing demand without a production of larger quantities of the heavy fractions than could be profitably marketed. Cracking also enables the production of petrol in *any* country, and close to the consumer, as heavy oils of high flash-point and low volatility are cheaper of transport across sea and land than the more unstable and dangerous products. The loss by evaporation of a highly volatile product is in itself a considerable item.

I predict that the day is not distant when every country that consumes petrol will be supplied with cracking plants for motor-spirit production from the most readily obtainable oil, erected near the points of its largest consumption.

In connection with this I might state that, in my opinion, the most economical future source of petrol production in Great Britain and in many other parts of the world will be in connection with the manufacture of water-gas for illuminating purposes, conducted at the existing gas-works, which are admirably suited for the purpose. There is much food for thought along these lines.

Water-gas is quite an important product in Great Britain, notwithstanding the comparatively low cost of gas coals, and the high cost of the oil necessary for its illuminants. In America, where oil is cheaper, water-gas is, I believe, much more extensively used. The whole topic is far too extensive for more than a cursory glance in such a paper as this, and I only mention it in connection with what appears to me as a very great possibility in the future.

Remember that there is used for carburetting purposes in the gas-works of Great Britain an amount of oil approximately equivalent to the amount of petrol consumed. The gas-oil is cracked at a high temperature into a fixed gas, and mingled with the water-gas to an extent sufficient to impart the necessary B.Th.U. and candle-power.

Now, in practising the process of cracking such an oil, a very valuable by-product can be obtained, i.e. instead of cracking all the oil into permanent gas, the operation might be so conducted as to yield at the same time a condensable amount of motor-spirit, say 25 to 50% of its entire volume, leaving the balance either in the shape of substantially the same gas that would ordinarily be obtained, or as a liquid residue equal in efficiency to gas-oil of commerce. Whether this balance of product is fixed gas or uncracked residual oil depends upon how the process is conducted, as I will explain later. But if this "run through" will yield, say, 40% of motor-spirit worth 10*d*. per gal., from gas-oil at 3*d*. per gal., one can readily see that the balance, 50% or more of the whole, would be obtained free of cost. More plainly stated—a water-gas works, operating a cracking process in conjunction, could produce a by-product to the extent of 40 to 50%, worth per gallon about three times the cost of the original raw material, and with a very ready local market for this by-product.

What the extra cost of such a production would be depends largely upon the process adopted, but 2*d*. per gal. on the spirit appears a very liberal allowance, and should also cover the refining. If such an estimate is correct, the motor-spirit would cost about 5*d*. per gal. Under such a supposition the oil for carburetting water-gas would cost 1*d*. per gal. against 2½*d*. to 3*d*. as at present (plus of course the royalty on rights to use such a process), and would yield in addition a profit in the sale of the motor-spirit above 5*d*. per gal. The gas-works are all located at points where there is a large consumption of petrol, and many of them are also provided with appliances for handling oil economically in large quantities. Furthermore, with a very cheap oil assured in this manner, it is probable that carburetted water-gas would very greatly increase as an article of manufacture, which would considerably augment the supply of motor-spirit from such a source. In fact it rather appears as if a sufficient amount might in time be thus obtained to supply the entire needs of the country, and without much fear of ruinous competition from the existing sources of supply. The general opinion is that motor-spirit produced by cracking oils, even if obtained at the very low cost claimed by some

inventors, cannot to any great extent compete with the two great existing companies, principally on account of the cost and difficulties of distribution. The enormous organisation of which they are already possessed would be difficult and most expensive to reproduce, but the situation would be very different if the local operations were conducted at gas-works where there would be very little necessary additions to overhead expense. Furthermore, in an isolated plant for the production of spirit by cracking, only about one-third of the total cost of plant is represented by the special apparatus, the bulk being for location, tanks, pumps, etc.

As near as I can ascertain, a gas-works could undertake the operation at about one-third the capital cost of a separate company, and its cost to conduct the manufacture would be almost as low in proportion.

At a gas-works there would be little or no waste, and every step of the operation could be conducted most economically and in a manner to give the greatest efficiency. A few of these circumstances may be worth attention. For instance, it is well known that a total cracking of oil into spirit is never accomplished in one operation, and that varying amounts of fixed gas and condensable residues are always obtained. The excess gas is usually calculated as fuel for the operation, but it is a very expensive fuel for that purpose. The liquid residues are usually run through a second time, but they are seldom of the same value for the purpose as the original oil.

At a gas-works only one run-through need be made, and it can be operated in a manner to yield the most satisfactory and economical results without any consideration of the amount of fixed gas produced, or the quality or extent of the liquid residues, for the reason that the permanent gas can be conducted direct to a holder, and utilised for enriching the water-gas along with that produced by complete gasification, as its composition is almost identical. The liquid residues have been found to be of about equal value with any gas-oil, and they can be mixed directly with it for the ordinary purposes of carburetting, and the converters or cracking stills can be much more economically heated by the cheap coke or breeze always present at the gas-works than they can by oil or oil-gas.

As near as I can calculate, a gas-works can produce motor-spirit by cracking for about 2*d*. per gal. less than it can be done in any plant solely conducted for the purpose. To this you can add at least 1*d*. saving in transportation, and probably 1½*d*. in selling costs. These amount to 4½*d*.—certainly a very considerable saving—but the matter goes much further than that. It really means

that as a by-product motor-spirit can be produced at gas-works, *at the very point of its consumption*, for about 5*d*. per gal. It is difficult to see how even the greatest companies, with all their distributing facilities, could ever meet such a competition if it came to a direct conflict, and if it should, the gas-works could simply shut off its motor-spirit production for the period when prices were not remunerative, and this without disrupting its organisation or leaving idle any considerable plant; this would not be the case for the competitor. Such low and unprofitable prices would in all probability not continue long, and when the trade returned to a profitable point the gas-works could quickly and economically resume operations. It would be practically impossible for even the strongest company, or for a combination, to "freeze out" competition of this kind, nor could they do it from control of raw material, as there are altogether too many producers of crude and residual oils very anxious for a market.

The present great producers of petrol may state that they can supply from ordinary distillation a sufficient amount for all future needs. But it is very clear that if the use of the high-speed internal combustion engine is to progress as rapidly in the future as it has in the recent past, additional sources of fuel will be required, and should be stimulated to as great an extent as practicable, and for this there appears to be no quicker or surer means than the cracking methods already so well proven.

I cannot lay too great stress on this recent operation of the Standard Oil Co., probably the greatest producer of petrol in the world. They surely read the "writing on the wall," and acted accordingly. There is another important point for the consideration of the motor user, and that is that the source of this supply of fuel has rested in too few, far too few, hands—one might almost say in two hands only—whilst those that can supply crude oil, fuel oil or distillates are far more numerous, and much less likely to be controlled by trade combinations. New fields with oil of only very small low-boiling fractions are constantly springing up and searching for a market.

Through efficient cracking processes Great Britain can easily produce in her own country any portion of her supply that she may desire, and the time may not be very remote when she can thus produce it from her own home-raised raw material. But that latter phase can hardly form a part of this paper. Later on I think it will be interesting for the members of this Association to hear papers on the subject of the possibility of Great Britain providing for all her requirements of oil and motor-spirit from her own resources.

I expect that you will feel that I have occupied considerable time in dealing with generalities, without yet saying anything about the technology of cracking. I have not overlooked that point, but I do think that a rough description of the present and possible future situation, generalities though they may be, is really of first importance. Now for the details of the operation. The term "cracking," I understand, was originated some 50 years ago by the still-men in the old Pennsylvania refineries, and meant just what its connotation conveys, viz. a partial alteration, as distinguished from the more complete decomposition which would disrupt the molecule largely into carbon and permanent gas. Cracking simply alters the molecules to an extent that produces an amount of low-boiling fractions that cannot be obtained by simple distillation, and may or may not be accompanied by any considerable production of permanent gas, the product being largely a liquid condensate, but of very different character from that obtained by simple distillation.

At the period referred to the object was an increase of lamp oil, for no one desired petrol, then an almost unmarketable article. Cracking to produce petrol is a very different matter from cracking to produce the far less volatile lamp oils, and, in fact, requires an entirely different operation, and one surrounded with much greater difficulties. It is with the latter alone that we have now to deal. I think that, fundamentally, it can be divided into two distinct methods—but with many ramifications of each.

One of these methods is the cracking in comparatively large stills, where the operation may be continuous or not, but where there is always a large volume of oil subjected to a high temperature for a considerable space of time with a slow speed of flow, and where in all cases certain and large portions are repeatedly volatilised and re-condensed, the hydrocarbon molecules being altered or re-arranged by these repeated shocks; whilst certain portions of the vapour, making a short circuit or channel, pass immediately out of the still unchanged, as a simple distillate, the larger portion may remain in the still for a considerable space of time, during which it is subjected to these oft-repeated shocks, that reduce its boiling point and gravity, an effect which is known as cracking. I have never found any uniformity in the spirit thus produced, and I have found its operation extremely slow, entailing a very much larger expenditure of fuel in comparison with the amount converted, and offering great difficulty in obtaining uniformity of operation. Condensation under pressure greatly helps the yield and quality of the product. My experiments in large apparatus have shown scarcely any spirit of the character of petrol obtainable without pressure condensation,

and even with such pressure the fraction boiling below, say 150° C., has been disappointingly small.

This is the method described in the Burton patent, but the actual results have never been published by the Standard Oil Co. The Burton patent claims that the spirit derived is largely of the paraffin series. I have a copy here of the affidavit presented to the United States patent examiner, in which it gives the sulphuric acid absorption of the Burton distillate as 20·2 %, and iodine number as 97, against 49·4 and 200 respectively on a similar cracked distillate condensed without pressure.

This question of the conversion of saturated into unsaturated oils by cracking, its effect and extent, is most important, and I will touch upon that later on.

The cracking in large stills, or in any vessels of large diameter, has never appealed to me, chiefly on account of the extreme danger.

The other fundamental method that I have mentioned is a cracking in tubes, when the process is one of continuity. This method has evidently appealed more strongly to most inventors, judging from the large amount of patents naming this style of retort. In it danger is largely eliminated. I have frequently had the joints or unions connecting such tubes leak, or even blow out, when operating with a large volume of oil under high temperature and pressure. And it was not even discovered except from the gauge in the receiving tank, showing a great decrease in production—or a higher temperature on the pyrometer—the vapours and gas simply burning in the furnace—as an unnecessary addition to the fuel employed. This factor of safety is in itself an element sufficiently strong to recommend tubes as against stills. Other considerations are the much lower cost of plant per gallon run through, and the far greater fuel economy. But there are also many difficulties encountered with tubes, not common to the still, some of which I do not think have been realised by the inventors of many of these patented processes. The principal one of these is the deposition of carbon, which, from my experience, cannot be avoided. This deposit increases with the extent of the conversion, and varies greatly with the oil employed, but it is always present to a greater or less extent, and its speedy and efficient removal must be provided for.

Many of the patents and processes heretofore described show continuous coils or tubes so arranged that there are no means of cleaning. This indicates to me that the inventor had never progressed very far in his experiments.

An oil, such as gas-oil, cannot be cracked to yield any large

percentage of converted product without considerable production of fixed gas and consequent deposit of carbon, and some of this carbon is sure to be deposited on the walls of the tubes. It may not be very noticeable at first, and runs of a few hours may not reveal it, but continuous running will surely do so. It is much more pronounced when a cracking operation is conducted at low than at high pressure, and at a slow speed of flow than with one of great rapidity. This is shown clearly by discharging the vapours and gases from the small cracking-tubes into a much larger receptacle, where the expansion drops the pressure to a great extent, and consequently reduces the speed. In this large receptacle by far the greatest amount of carbon deposit will be found. I make great use of this feature in the cracking which I conduct, permitting the products issuing from the cracking-still under their full pressure, which may be 50 to 75 lb. per sq. in., and at a speed as high as 5000 to 6000 ft. per min., to pass into a receptacle of say 16 times its diameter. This sudden expansion and great reduction of speed throws out most of the carbon; a rough guess might place it at 99 % of all the carbon formed. This receptacle is not a dephlegmator, as its temperature is maintained at a point about that of the highest-boiling fractions.

In my early experiments it was found that the carbon thus expelled attached itself firmly to any metal surfaces, so we increased the size of the chamber, and filled it with small fragments of metal, selecting short pieces of thin ¾-in. pipe about 1 in. long. These are soon coated with carbon. They are easily removed by dumping through the bottom, a fresh charge being admitted at the top. The carbon is easily removed from this filling material by burning it off in a small furnace devised for the purpose, so that the filling may be utilised almost indefinitely.

Notwithstanding that the bulk of the carbon is thus extracted, there is nevertheless some deposited on the tubes of the cracker, provision for the removal of which must also be made, not alone on account of danger of ultimate plugging, but also because any coating on the walls reduces the thermal efficiency of the retort, requiring more fuel and lessening the yield.

We found that the carbon was easily removed by blowing compressed air through the heated tubes. The carbon combustion is very rapid, evolving volumes of sparks; when these cease, the tube is clean. There is no danger of destruction of the metal, as the air is turned off the moment the sparks cease, and at the same time the temperature quickly drops owing to the cessation of combustion.

This cleaning can be effected by removing the nest of tubes from

the retort, or even can be done in the furnace without removal by a simple opening in the connections, so that by the mere removal of a plug from the top of the vertical branches a moment's blast of high-pressure air removes the carbon completely.

These nests of tubes are also arranged for speedy removal *en bloc*, by simply disconnecting two unions, lifting the whole nest on an overhead trolley, and dropping in a new set. Such a transfer can be made in less than thirty minutes.

The entire cost of a nest of 1-in. tubes with all connections is approximately 15*l*., and their destruction appears to be very slow. In fact, I have never burned out or ruined a single tube, except when experimenting with water or in various other cleaning experiments.

I have given considerable detail to this specific operation of cleaning tubes and removal of carbon, which you may think are mere details of shop practice, but without ready and effective means for this purpose cracking in tubes is impracticable, and many experts have advanced this deposit of carbon and consequent plugging as a great objection to the tubular system, as compared with the larger still, where such deposit can be easily removed.

I have heard that some so-called experts in hydrocarbon claim that all carbonaceous deposit may be prevented by the admixture of water with the oil—that the steam produced in some way prevented the separation of carbon. Well, all I can say in answer to that is, that those making any such claim could not have had any considerable personal experience in making tests with and without steam on anything greater than laboratory apparatus. Steam may be of some help in that direction, but not sufficiently to be in any way commensurate with its cost.

It must be borne in mind that even rather more calories are required to elevate and maintain the temperature in a gallon of water than in a gallon of oil. Hence the fuel required increases in *at least* the same ratio according to the percentage of the water used. Then also the cost of plant is increased in like proportion, as its capacity is governed by the total liquid run through. As most of the processes employing water require from 20 % to 50 % for admixture with the oil, the increase of cost in these two respects mentioned can be readily appreciated. It must be borne in mind that, apart from raw material, the cost of fuel is the greatest item in the cracking process, and anything that increases this cost is a tremendous disadvantage. When very small diameter tubes are used, say $\frac{3}{4}$-in. to $\frac{1}{2}$-in., an addition of water may be helpful in retarding the clogging, but in commercial practice such small tubing would be far from economical. With a gas-oil, tubes of such sizes

would choke in a few hours of continuous run. An addition of water would enable a longer run to be made, but on larger tubes I have found it of no benefit, and very annoying, causing irregular pressure. Most of the past experimenting has been done on small tubes, and perhaps that is one reason for the use of water. At all events, I have found steam totally inadequate as a means for preventing carbonaceous deposits.

Again, on very large tubes, 4 in. to 6 in., the use of water has been found effective, and I might say necessary, but for an entirely different purpose, its object being to lessen the production of fixed gas, due in consequence, presumably, of its effect as a regulator of temperature. In large tubes, whether open or filled with material, there is a tendency for the vapours to short circuit or channel, and there is more difficulty in imparting the desired temperature to the interior of the mass.

Also on such larger tubes, thick walls are necessary, and a higher external temperature is required. The periphery being hotter than the interior, there is a tendency for the superheating of such portions of the vapours as find their way to the surface. In that case these vapours are likely to be decomposed into permanent gas and carbon.

If steam is used, it acts as a corrective, an equaliser of temperature, and preventative of extreme local heating, thus to some extent lessening decomposition of these sensitive vapours. Yet, in the only case with which I am familiar, when this process was tried on full commercial-sized apparatus, the amount of gas produced in each run-through was equivalent to the amount of refined spirit derived, but in this case, on account of the very large tubes, about 6 in., the external heat required was so great, that a very extensive decomposition of steam occurred. The extent of hydrogenation was hard to determine, but at all events the spirit produced was so largely unsaturated that hydrogenation could not have been of much consequence. Although we do not know what became of the small amount of hydrogen evolved, we do know that the oxygen set free was sufficient completely to destroy the tubes in a surprisingly short space of time.

It has been contended by some that the oil film on the surface of the tubes would prevent their oxidation, but from the results that I have alluded to and others that I have personally obtained, I am quite certain that it has very little of this desired effect.

Further, the only reason why this has not been known before, is that the apparatus was not operated for a sufficient length of time to develop these conditions. I know of only one

instance, where a process utilising water has been conducted on anything approximating to commercial conditions, and in that case a large and very expensive plant was erected, after what appeared to be sufficiently successful preliminary trials, only to discover that in continuous operation the tubing was most rapidly destroyed.

As far as any advantage from the use of water as a hydrogenating agent is concerned, I am sure it is *nil*, whether with or without a catalytic combiner, and I have operated fair-sized apparatus for weeks with nickel and other so-called catalizers, first with and then without water, and we could never notice any material difference. If hydrogen without oxygen is utilised, better results are obtained, but the expense appears to be prohibitive. With nickel rods in the tubes, and with water used with the oil, I have found the rods so heavily coated after a six- or eight-hour run, that the coating could only be removed by buffing. It was impossible in any way to wipe it off. The substitution of copper for nickel rods gave equally poor results. In large tubes, 1 in. or more, water in excess of 8% or 10% is utterly impracticable, if the process is conducted under pressure and at any rate of feed that would be commercially economical, as no uniform pressures can be maintained.

In a cracking process the ideal appears to be its conduct at a temperature sufficiently low to produce not more than 20% or 30% of unsaturated hydrocarbons in the finished product, with some means of removing the cracked vapours, i.e. the sufficiently low-boiling fractions, at the very temperature of their formation, conducting them immediately towards a cooler atmosphere, in order to prevent their further decomposition into permanent gas and carbon. I have succeeded in accomplishing this to a very considerable extent by a method which I think is novel, and which at least has proven effective, when conducted in large commercial apparatus, though I have not been able fully to reproduce such results on a smaller scale, in consequence, I presume, of the difference in mass reactions. The conduct of the process is as follows:

The oil is fed at a rate exceeding 70 gal. per hour through inch tubes of more than 300 ft. in length, under 50 lb. to 75 lb. pressure, and so throttled that the speed of the vapour through the tubes exceeds 5000 ft. per min. The oil is first vaporised in a coil, preheated in the flue by the waste heat of the products of combustion from the furnace, so that it enters the cracking tubes at a high rate of speed. The speed is so great that very little deposit can be formed in these tubes to choke them and interfere with the cracking action, but, as the passage of the vapours through the tubes occupies only about three seconds, no very extensive cracking occurs, as is proved

by samples extracted at these points. The temperature read on a pyrometer, its thermal couple being located in the centre of the tubular nest, is about 550° C.

The vapours issuing pass into a vertical pipe of twelve or more inches internal diameter and about 12 ft. high, entering it through a very confined space acting as a throttle, and preferably impinging against a baffle in the large pipe, so that the speed of flow is instantly reduced from about 6000 ft. per min. to a very nominal rate. This converts the energy of speed into that of heat, a sort of degrading action, much the same as takes place in a throttling calorimeter, the temperature actually increasing some 30° C., notwithstanding the expansion due to a reduction of pressure from 50 lb. or 75 lb. to about atmospheric. Hence we have in this large pipe, which is well insulated, a temperature well above that existing in the inch tubes of the cracker, and as the speed through this large pipe is comparatively slow, a large amount of cracking therein takes place with no extraneous application of heat, affording no chance for a superheating of the vapours to a temperature higher than that at which cracking takes place.

By this method the interior of the mass is hotter than the exterior wall of the container, and all the vapours in their upward passage are working towards a cooler condition, thus preventing local superheating which has always produced the largest amounts of fixed gas from what would otherwise have been condensable product of the character most desired in motor-spirit.

This pipe is filled with the small pieces of thin tubing before-mentioned, which present an enormous surface to collect all the carbonaceous deposit.

One might think that this very large chamber, with all its surfaces, and with the slow passage of vapours through it, would act as a dephlegmator rather than a cracker, but in actual practice, even with oils of a gravity exceeding 0·960, and some very high-boiling fractions, no liquid condensate has ever been collected from the bottom, and the higher the rate of feed of oil, at the same temperature in the cracker, the higher is the temperature in this secondary cracker.

The actual temperature of the vapour in the lower portion of this receptacle may exceed the external temperature of the tube near its exit, but inside the furnace, by about 30° C.

From this receptacle the vapours pass through dephlegmators, that separate all fractions boiling below the chosen point of cut, and the vapours and gases passing on are conducted without further condensation, and at a depression, into a mechanical compressor

working under 70 lb. to 100 lb. per sq. in., and then condensed through a cooler under that pressure. The object of the compressor is two-fold. Firstly and of least importance, it is a means of drawing these vapours at substantially atmospheric pressure through the secondary cracker and the dephlegmators; and secondly, it is a means of chemically attaching to the condensable liquid the gases that would otherwise be permanent.

That any chemical combination between such gases and liquids could thus take place has provoked much question and scepticism, and has led to very extensive tests. It was generally contended that its function could be only that of creating a solution of a gas in a liquid. That an actual and important chemical reaction does take place has now, I believe, been established to the satisfaction of some of our best experts.

The best pressure, if any at all, under which to conduct the cracking operation is a very moot question. It has been tried at all points from a condition of slight vacuum up to as high as 1500 lb. per sq. in.

In a simple cracking operation I think one can say that as high a pressure is desirable as is practicable within the limits of the apparatus.

The consumption of fuel increases with the pressure employed, but the production of fixed gas appears to decrease. In respect of economy I have found pressure advantageous. Above a certain point, however, as pressure is increased, the size of the tubes must decrease, and the cost of the plant increase. All vapours and gases are extremely penetrating, and it is very difficult to maintain tight joints under high pressures. I have experienced great difficulty in that respect with pressures exceeding 100 lb. I am aware that some very able experimenters pin their faith to extremely high pressures, but it appears to me that they must require very heavy and costly tubes, and of too small diameter to be practicable on a large commercial scale.

After a great deal of experimenting I have adopted 50 lb. to 75 lb. as the pressure that, all things considered, gives the best results. At such a pressure common heavy iron pipe is quite satisfactory.

No set of cracking tubes can continually be kept under full temperature. They must frequently be cooled to permit of cleaning, and the expansion and contraction of large unions or joints greatly enhances the probable development of leaks.

The maintenance of the exact temperature requisite to the nature of the oil under treatment is of much greater importance than has, I think, been realised. A change of a comparatively few degrees makes enormous differences in the quality of products and in the

production of gas. The usual method of determining the temperature is by placing the thermo-couple of a pyrometer in the centre of the nest of tubes, but that only tells a part of the story. The temperature of the vapours in the interior of the tubes may be far less than that at the exterior, depending upon the speed of flow. The length of the tubes should be in reasonable ratio to the diameter.

Supposing the external temperature in the centre of the nest is 560° C., a change from 20° below that point to 20° above may make a difference of 50% in the production of gas, and a great difference in the gravity of a spirit boiling below a given point, but still more marked is the difference in the unsaturated portions. I have seen this 40° difference in temperature make 40% difference in the unsaturated portion. I have seen a spirit produced of 90% unsaturated, and another of only 30% unsaturated, both from the same oil, with the same point of cut and the same pressure, in fact, with all conditions the same except this comparatively small difference in temperature.

I can say with all assurance that high temperature makes for high unsaturation, which has been considered a very great objection to spirits obtained by cracking, a view with which to a certain extent I agree. As, however, the temperature declines below a certain point, the conversion into spirit most rapidly declines. There are methods of converting unsaturated into saturated hydrocarbons otherwise than by hydrogenation, but that is not part of a cracking process, to which I am limited to-night.

To just what extent unsaturated hydrocarbons are objectionable, is questionable and subject to a great difference of opinion. The general opinion is, that being loosely combined, they are much more inclined to give a smoky exhaust, and to form carbon or soot deposit in the cylinder and on the plugs. I have not found that to be the invariable case when judged from long tests. Any large portion of unsaturated hydrocarbon in a cracked spirit is, however, extremely objectionable, but for another reason, viz., that the resinous carbon colloid, so common to cracked spirits, exists largely, if not wholly, in the unsaturated portions. This is the matter that gives to cracked spirit the varnish-like odour that is frequently so noticeable, and which crude cracked spirit, before refining, always possesses to a greater or less extent.

This crude, cracked spirit, as far as I have seen, is always of a yellow colour, varying from light lemon to deep orange, but the odour is not wholly due to the resinous colouring matter, nor to the percentage of unsaturated compounds, and the colour and odour vary greatly with the character of the oil that is used. Some fully-

saturated oils may give a very deep-coloured crude spirit, and some quite unsaturated oils may give a very light-coloured crude spirit. I can show light lemon-coloured spirit of which 80% is unsaturated, and dark, almost port-wine-coloured ones with 40% or less, so that colour is no absolute criterion. This resinous substance is very peculiar in many respects, and varies enormously in its chemical composition.

I was originally of the opinion that it rested entirely in the colouring matter, and that it was extracted with it when the spirit was refined to a water-white. That certainly is the case to a considerable extent, at all events the greater part of the peculiar disagreeable odour of a cracked spirit disappears upon its decolorisation, but frequently it will acquire it again by ageing and yet remain fully water-white.

It appears to be a product of slow oxidation, for frequently, if a spirit subject to this form of decomposition is kept in a receptacle for some time, with some air, a resinous red varnish deposit is formed on the bottom, and the whole mass has a strong varnish-like odour. Such a spirit, when fresh, if evaporated over a water-bath may show no deposit, yet, if allowed to evaporate slowly in a beaker, the last fractions may be a heavy red varnish. A spirit with such tendencies will eventually clog and stick up the valves of any engine in which it may be used.

Although this varnish-forming product is a result of the cracking process, it is not inherent to all cracked spirit. It is a product of high temperature, but very complete cracking can be done at a temperature so uniformly low that the objectionable product does not exist to any important extent. It is just on this particular that in my opinion the whole future success of the cracking process rests, and I cannot lay too great emphasis upon it. Bear in mind that decrease in temperature, below a certain point, means decrease of conversion, and decrease in conversion means increase in operating cost. Drop the temperature to a point when these resinous products are not created, and the yield of spirit may decrease to a point below that of profit.

Now, how are such conditions to be met? One way is to mix the cracked and largely unsaturated spirit with a fully saturated petrol in such proportion that a proper balance will be obtained, but a cracked spirit that can only be used in such a manner can only constitute a makeshift. Another way is to saturate the unsaturated portion. This we know can be done by hydrogenation, but thus far it has proved altogether too expensive for commercial use.

One way that I hit upon and practise is to operate at a temperature sufficiently low to be comparatively free from this danger, and without regard to any large conversion in the heated tubes, and then to combine the gases with the condensable vapour, in the manner which I have herein described. It is a method quite contrary to that heretofore employed, particularly such as are used in the natural gas-fields of America, or in producing the casing-head gasolene, wherein a so-called wet-gas is highly compressed, or subjected to repeated compression in the presence of a liquid hydrocarbon, the process being usually accompanied by refrigeration. In that case, little more than the solution of a gas in a liquid is obtained, and a very wild, unstable and dangerous product obtained, although one that has already come into extensive use.

The amount of easily condensable fractions that are contained in a gas derived by cracking an oil are so small in proportion to the whole, that simply its addition would not constitute any very considerable gain. We have scrubbed such gases in the most effective manner, obtained the condensable portion, and calculated to what extent it would increase the yield from its simple addition. This has amounted to from only 5 to 8 % against an average increase of fully 33 % by its *attachment* in the manner which I have adopted; but the most important point is that this 33 % addition is *all* of the lightest gravity and lowest-boiling fractions, and makes an excellent working motor-spirit out of one that would otherwise be of little value.

This 33 % of increased light fractions is not gas in solution. The proportionate increase is sufficient to disprove such an assumption. But there are many other proofs, perhaps the most important being that gas held simply by solution is largely dispelled by distillation. Yet this spirit can be several times distilled with very little loss of the fractions boiling at the lowest points, and this, when the condensation is at a normal temperature, conducted into an open vessel with no pressure. (I have several of such fractionations here.)

The gas is affixed to the ordinarily condensable vapour by the action of a single-acting mechanical compressor, working under from 75 lb. to 125 lb. pressure per sq. in. The vapours and gases issuing from the cracking stills are passed through the dephlegmators, which remove the pitch, loose carbon and all fractions boiling only above the point selected for the cut, for instance 165° C. The fractions not condensable at that temperature are passed without further cooling, along with all the gas, into the cylinder of the compressor, wherein an endothermic chemical reaction takes

place, as indicated by the decrease in temperature. If no endothermic reaction took place, the condensation of these vapours and compression of the gases would create an increase of temperature, so the heat absorption of the reaction is sufficient, not only to offset the natural physical increase that *would be expected*, but to reduce it still further—many tests showing a drop of temperature of fully 30° C. between the inlet and the exit of the compressor, and this when it is operated without water in the jacket, the readings being taken by thermometers placed so their bulbs were as close to the moving piston as was practicable. I have here some of these records that were made on a comparatively small-sized apparatus, the inlet pipe being 1 in. and the exit ⅜ in. diam., so that the decrease of heat could not come from any possible expansion. The vapours entered the cylinder under slight depression and were discharged under 125 lb. pressure.

Comparative runs were made on air, City gas, and steam, all superheated to the same extent, and in all these cases there was developed, as would be expected, a very considerable elevation of temperature. For further comparison, samples were extracted and condensed just before and just after the compression, showing an entirely different product both in fractionation and in bromine absorption, and, as I have previously stated, the condensate was increased some 33%. The full records of these tests are before me for the inspection of any who may be interested. Time and space prevent my including them in this paper.

Before closing this rather long drawn-out paper, I feel that I must say a few more words in regard to the quality of the spirit produced by any cracking process, since by this to a considerable extent the ultimate success of the process must be determined.

There has been much prejudice against spirits produced by cracking, principally on account of their odour. In this respect a great deal depends upon the oil used, and the method in which the heat is applied. If there is extreme local heating, the spirit obtained is almost certain to possess a very objectionable odour, even though it may contain far less unsaturated percentage than a spirit cracked at a higher temperature, but at one more uniform throughout. The explanation of this I presume is, that if even only very small portions have been extremely overheated, they may suffice to impart the objectionable odour to the entire liquid. Furthermore, a great deal depends upon the method of refining. My experience has been that a cracked spirit refined by sulphuric acid (even though very small quantities are used) invariably possesses much more of the sweet aromatic odour than the same spirit refined with fuller's

earth. But some spirits obtained by cracking cannot satisfactorily be refined with fuller's earth, whereas others are extremely responsive to such a treatment.

I can say with all assurance that a spirit can be produced by cracking, that is entirely free from any objectionable odour in the liquid state, and gives an exhaust from the engine in which it is used as free from odour as that of petrol.

I have used such spirits for several thousands of miles in several motor-cars without any trouble from the sooting of the plugs or carbonising of the cylinders. I have not found that there is any more tendency for a smoky exhaust than there is with petrol, provided that a sufficiency of air is supplied to produce the best explosive mixture.

The higher the gravity of a spirit the more air is usually required for its complete combustion, and if the engine is operated so that the exhaust is clean, I have not found any tendency to the sooting of the plugs. It is not necessary to alter the set of the carburettor from a proper adjustment for petrol consumption, although a somewhat increased mileage will be obtained if the mixture is given a slight increase of air. There is a trouble that has been occasionally encountered in changing from petrol to a cracked spirit or to benzol, in that, very frequently, the carburettor is not adjusted to give the best results with petrol, the mixture being too rich ; it is frequently so arranged in order to insure easy starting, and then when a change is made to a spirit that requires more air for its perfect combustion, the air admitted being often insufficient for the best results on petrol, there will be with the heavier spirit a tendency to smoke, and, consequently, for sooty deposits upon the plugs. This is all very easily corrected in any engine that is arranged with an adjustable air intake.

Although in the average spirit produced by cracking there is more odour than that of standard petrol, the odour is infinitely less than with benzol. It is absolutely certain that spirits can be produced by cracking that have no more odour than standard petrol.

Almost any cracked spirit will give more mileage than petrol, and the average of many extensive tests that I have made or caused to be made both on the bench and on the road have shown an increased mileage of from 15 to 20% over that of petrol, or about the same as that of benzol, gauged by volume, not by weight. Another great advantage in the use of spirits produced by cracking is the freedom from knocking from pre-ignition when the engine is operated with the spark advanced to the proper point. Benzol also is possessed of this advantage, but a good cracked spirit is even

superior in this respect to benzol. Its freedom from pre-ignition is a very great advantage, particularly in the modern engine of high compression.

These engines as a rule are very sensitive in the matter of knocking, requiring a constant adjustment of the spark, and pre-ignition creates great wear and tear. I have frequently driven a car on a cracked spirit with the spark fully advanced on the high gear up steep inclines until the car came practically to a standstill without any knocking being noticeable.

This means that much less changing of gear is required, far less racing of an engine, and, in general, an engine that is running slowly consumes considerably less fuel than when operated on a lower gear with more rapid revolutions. It is due to this, I believe, that the increase of mileage over regular petrol appears to be even greater on road-tests than on bench-tests.

I presume the explanation of this phenomenon is that, compared with light petrol, the spirits produced by cracking have slower combustion, although, owing to their extremely low flash-point and very low initial boiling-point, the ignition may be even more rapid. The slower combustion imparts a force for the whole length of the piston-stroke, instead of the instantaneous combustion of the whole at the point of ignition, in this respect being somewhat similar to the action of a slow-burning gunpowder as compared with one of greater rapidity. Another reason is that the explosion is not so likely to take place at the lower point of compression.

The following paper, dealing with the more academical aspects of the same subject as the foregoing, was then read by its distinguished author, and the subsequent discussion of both contributions to the literature of this very important and still obscure region of technical and scientific investigation will be found on pages 176 to 185.

The Chemistry of the "Cracking" of Heavy Oils.

By Professor VIVIAN B. LEWES, F.I.C., *Member*.

THE term "cracking" is one of those delightful Americanisms which express so exactly the meaning we wish to impart. that it has been adopted universally—when a molecule is decomposed, it is broken up: when it is merely resolved into simpler compounds, it is "cracked." The term first came over with carburetted water-gas, when the oils fed into the carburetting chamber were said to be "cracked," i.e. converted into hydrocarbon gases of high illuminating value, but not "broken" into carbon and hydrogen.

A less violent form of the same operation can be utilised to convert the heavy hydrocarbon molecules in oil of high specific gravity and boiling-point into the volatile liquids available for use in the internal-combustion cylinder of the motor-car, and the rise in price that petrol underwent three years ago led to many so-called "inventions" for the production of petrol substitutes being exploited.

Some were well thought-out processes, some were "inventions" pure and simple, a few have lived through the initial experimental stages, most have died in the transition from the stage of a laboratory experiment to the status of commercial working, and many were based more or less on a paper read by the present Sir Edward Thorpe and John Young before the Royal Society in 1871. This now historical memoir was the first and only really scientific attempt to explain the actions that led to an increase in the yield of light hydrocarbons from a heavy oil under certain conditions of distillation that had been, I believe, first noticed in America in 1861, and were patented in England by James Young in 1865.

My excuse for bringing this paper before you to-night is the interest taken in the subject at the present time, and a hope that a translation of the facts discovered by Thorpe and Young by the light of modern practice may be of use to some members of the Institution.

Thorpe and Young took 3½ kilos of paraffin wax obtained from shale and distilled it in an iron mercury bottle connected with a second by a bent tube carrying pressure-gauge and stop-cock. The distillation was carried out over an open coal fire, one bottle containing the paraffin being heated, whilst the other acted as a condenser. In about 4 or 5 hours the distillation was completed,

the pressure throughout being kept at 25 lb., and a magma of oil and unaltered paraffin resulted, which could be liquefied completely by the warmth of the hand. Four litres of liquid hydrocarbons were obtained, and on a preliminary fractionation gave—

Below 100° C.....	0·3 litres.
100—200° C.....	1·0 „
200—300° C.....	2·7 „

Repeated distillations of the portion boiling below 100° C. resolved it almost entirely into 3 fractions—

(1) 32—38° C., and consisted of pentane and amylene
(2) 65—70° C. „ „ hexane and hexylene
(3) 94—97° C. „ „ heptane and heptylene.

Members of the acetylene and benzine series were absent.

Extended experiments with the portions distilling from 100 up to 300° C. and the solid hydrocarbon left above 300° C. showed them to be mixtures of saturated hydrocarbons and olefines.

In the fractions distilling below 100° C. these two classes of bodies are in nearly equal proportions, but above that temperature the proportion of paraffin hydrocarbon to olefine becomes gradually larger as the molecular weight increases.

The authors emphasise the fact that comparatively little gas was evolved, and make no mention of any separation of carbon or heavy residues left in the retort from which the wax was distilled. Indeed, it seems from the memoir that neither the separation of carbon or formation of tarry residues took place, as preliminary experiments are described in which paraffin wax in a bent tube was distilled in a gas combustion furnace from the end containing the wax to the cooled end; then the tube was reversed and the distillation repeated, and after a dozen distillations the distillate remained permanently liquid, and consisted of a mixture of saturated hydrocarbons and olefines.

The conclusion the authors draw from their valuable research is that the simultaneous formation of a saturated hydrocarbon and olefine must be assumed to occur from the loosening of the affinities of certain of the CH_2 groups in the heavy paraffin molecule, and their recombination to form unsaturated hydrocarbons, but that the evidence is not sufficient to justify any assumption as to the exact manner of this decomposition.

I have made a very large number of experiments on the cracking of heavy oils, and by interpolating some of the results obtained I think we can gain a fairly clear idea of the general trend of the actions taking place.

In the formation of simpler hydrocarbons from more complex

the important factor which governs the course of the reaction and the nature of the new compounds is the degree of temperature employed, and this is not given in Thorpe and Young's paper, but the specific gravity of the paraffin wax and also its melting point were carefully determined, and from these we know that its boiling point was about 225° C. The pressure however under which it was distilled was 25 lb., so that the temperature used in the action could not have been much over 300° C., and it would be quite safe to say between 300° and 400° C. At this temperature the reaction would be a dissociation and not a decomposition, the difference between the two being that in the former case under favourable conditions recombination would take place between the products to form the original body, whilst in a decomposition the products remain separate.

That it is dissociation acting in this case is shown by the fact that if the paraffin wax is heated in a straight sealed tube for 12 hours no change in melting point or composition ensued, but when transferred to a bent tube, and distilled backwards and forwards six times it became completely liquid.

In the straight tube, all at a high temperature, there was no separation by condensation of the dissociated parts of the molecule in the vapours, and they recombined, but in the bent tube each distillation and separation built up lighter compounds which were not dissociated again at the temperature and pressure capable of divorcing the groups of the heavier molecules. The fact that a temperature that will dissociate a heavy molecule is insufficient to break up lighter ones is made clear by the authors, who took the fraction of oil boiling at about 255° C. from a previous make of cracked hydrocarbons, and distilled it backwards and forwards in the bent tube twenty-one times without altering its boiling point or bromine absorption. Indeed, they went so far as to say, "It appears that only paraffins boiling at an extremely high temperature and those usually solid under ordinary conditions are thus susceptible of decomposition. The readiness with which they yield liquid hydrocarbons appears to depend upon the complexity of their constitution.'

They were undoubtedly right *for the temperatures they employed*, but neither they nor the many who have devised cracking processes since have grasped fully the fact that every simplification of the hydrocarbon molecule requires a higher temperature for its further dissociation, and that where an oil is cracked, the largest portion of which distils between 100° and 200° C., one must use a temperature liable to overcrack, i.e. decompose the fractions of oil distilling at

300° C., with the resulting formation of tar, gas and choking with carbon.

Starting with the assumption that Thorpe and Young's experiments were carried out at a temperature probably about 300° C. and under a pressure of 25 lb., we have the conditions under which a heavy paraffin hydrocarbon of uniform or nearly uniform composition could be cracked into liquid hydrocarbons with but little gas and no residue of carbon, and as at the present time the whole interest in such processes centres in the production of motor-spirit, it would be well to try to get an idea of how it compares with some of the processes that have been brought forward lately in yield of spirit distilling below 150° C.

3½ kilos of the wax, having a melting point of 45·5° C. with a specific gravity of 0·906, were taken, which in the liquid state would occupy 0·63 gallons. 4 litres of liquid were obtained, 0·75 litre of which distilled below 150° C. or 0·165 gal., this being equal to a conversion of 26 % of the original wax into motor-spirit, which, considering it was a simple distillation from one iron bottle to another, must be looked upon as a remarkable result.

Directly decomposition begins to take the place of dissociation, the fact is made manifest by the evolution of gas—one cannot have satisfactory conversion unless some gas is being evolved, that is to say, the temperature must be high enough to bring about incipient decomposition in the heaviest molecules in order to ensure dissociation in the most abundant and lighter compounds, but excessive gas means not only heavy waste of hydrocarbons but thickening of residue by tar and deposition of carbon.

The amount of gas evolved, when it can be measured, is as good an indicator of the correctness of the temperature as an analysis of the gas is of the character of the conversion. The quantity and character of the gas evolved will of course vary with the oil used, but as long as it is a mineral oil residue, the results are fairly concordant for the same temperatures.

The class of oil most often employed for cracking work is the fairly cheap grade after the benzine and lighting oil cuts have been taken off, such as Solar Distillate, and an experiment that affords a good deal of information is the simple cracking and decomposing of such oil by running a thin stream into an iron retort heated to definite and carefully-maintained temperatures, in much the same way as if the object was to make oil-gas.

The data of such an experiment will illustrate what I mean—

Oil used: "Solar Distillate."

Specific Gravity: 0·865. Flash Point: 149° F.

Distillation—

1st drop	110° C.
4%	170° C.
10%	238° C.
15%	246° C.
20%	252° C.
25%	255° C.
30%	267° C.
35%	271° C.
40%	276° C.
50%	285° C.
55%	291° C.
60%	320° C.
65%	343° C.

Thermometer rising rapidly.

If the oil be now heated in a retort under ordinary pressure, no signs of decomposition will show until about 400° C., when gas will begin to be evolved, and will increase in quantity rapidly with rise of temperature until about 1000° C. is reached, when it is loaded with soot, and all the hydrocarbons are undergoing rapid decomposition. The volume of gas evolved per gallon of oil treated is shown by the following table:

Temperature of retort	500° C.	700° C.	900° C.	1000° C.
Cub. ft. of gas per gal.	12 cub. ft.	60 cub. ft.	72 cub. ft.	84 cub. ft.

The analyses of the hydrocarbons in the gas given off at various temperatures are:

	500° C.	700° C.	900° C.	1000° C.
Unsaturated hydrocarbons.	39·13	36·56	36·55	22·04
Saturated hydrocarbons ..	42·41	49·45	49·45	54·83
Acetylene	0·05	0·08	0·38	0·46

For such an oil cracked without pressure, 500° C. would be the temperature likely to give the best results, as we see from the table that only 12 cub. ft. of gas per gal. are being formed, so that wastage of oil is small, whilst the proportions of saturated and unsaturated hydrocarbons are near together, and reflect the proportions in which they would be formed in the liquid residuals.

If this oil was passed slowly through a long coil of tube heated

to 500° C., and then to a cooled condenser, the yield of spirit boiling below 150° C. would be low, and to increase the yield in a given time pressure is resorted to. Cracking under pressure acts advantageously in two ways: in the first place, it increases the boiling point and the temperature of decomposition, so that a temperature of 600° C. might be employed without any more wastage than at 500° C. and with a considerable increase in the conversion, whilst in the second place it causes the absorption and polymerisation of some of the nascent fragments of heavy molecules, and so adds to the volume recovered.

It must not be supposed for a moment that because Thorpe and Young found the products of cracking a simple paraffin compound at a suitable temperature to be only olefines and simpler members of the paraffin series, the same easily traced compounds constitute a modern cracked spirit. We have been forced by commercial considerations to deal with a residue oil containing nearly all the members of the paraffin series from nonane upwards, and whilst we have been regulating our conditions of working to suit the largest fraction of our oil, we have been decomposing the higher fractions and undercracking the lower, with the result that the spirit obtained contains not only the primary products of dissociation, but also the secondary products of their further decomposition and interactions.

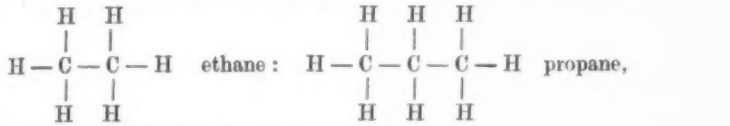
Solar oil as far as regards the percentage proportions of carbon and hydrogen would correspond most nearly to dodecane, $C_{12}H_{26}$, although it is a mixture of this with higher and lower members of the same group. Let us suppose for a moment that it is pure dodecane, in order to trace in as simple a form as possible the course of the actions, analytic and synthetic, that take place when dissociation loosens the molecular bondage in which the carbon radicles are held.

In representing the structure of hydrocarbon compounds, graphic formulæ are often employed to explain such phenomena as Isomerism, and the fact that two compounds identical in their ultimate chemical composition decompose in quite a different way.

The tetravalent nature of carbon demands that when fully saturated with monovalent hydrogen four atoms of the latter should be combined with it, and we have:

$$CH_4 \text{ or } \begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array} \text{: Methane}$$

Methane is the first member of the paraffin series of hydrocarbons, C_nH_{2n+2}, and the higher members of the series are built up by the progressive addition of the group $-CH_2-$, so that we get—

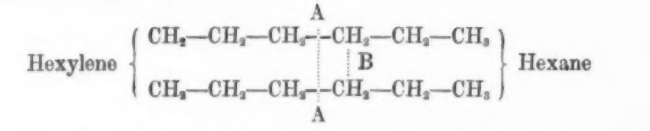


and so on for the whole series.

In what are called constitutional formulæ the same thing is shown by writing each group together, and propane would be—

$$CH_3—CH_2—CH_3$$

The Paraffin and Olefine series are all open-chain hydrocarbons, but there is no necessity to write them in one line : dodecane, for instance, might be written :



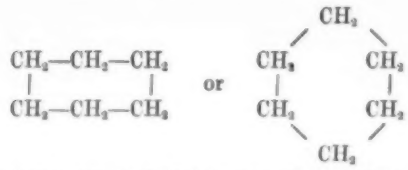
And on dissociation this may be imagined to split up, as shown by the dotted line A A, into the olefine hexylene, whilst the CH_3 groups on the right of the line of disruption become bonded together with the CH_3 groups as shown by the short dotted line B, and form the paraffin hexane.

These facts we learn from the researches of Thorpe and Young, but there is another point about this decomposition which I have never yet seen noticed, but which plays a most important part in the further decompositions. If the hexylene as formed be taken—

$$\begin{array}{l} CH_2—CH_2—CH_2— \\ \quad\quad\quad\quad\quad\quad | \\ CH_2—CH_2—CH_2— \end{array}$$

we find it has two unsaturated affinities which give it its place as an unsaturated hydrocarbon, and on bromination the power of forming an additive compound, i.e. absorbing it without any evolution of hydrobromic acid.

Under the ordinary conditions of commercial cracking, the two free bonds often—indeed mostly—satisfy each other, and convert the compound into a member of the closed carbon ring series of naphthenes—hexahydrobenzol.



These napthenes are identical in composition with the olefines: both hexylene and hexahydrobenzol would be represented by the empirical formula C_6H_{12}, but when we study their reactions and decompositions, we find they are wholly different; hence the olefines and naphthene series are said to be isomeric.

When we attempt to brominate a napthene, instead of forming an additive compound, it will form only a substitution body, hence hydrobromic acid is formed, whilst sulphuric acid of a strength that would dissolve an olefine has little or no action on the corresponding naphthene—a fortunate thing for the manufacturer of cracked spirit who desires to purify it by the ordinary acid process.

The great difference however between the olefines and their isomers the naphthenes is in the decompositions they undergo when further heated: as whilst the olefines split up into simpler members of the same series, then into acetylene and methane, and finally into carbon and hydrogen, the naphthenes shed off the extra hydrogen atoms, and are converted into aromatic hydrocarbons such as benzol, toluol, xylol, etc. A very interesting point to the student of petroleum is that naphthenes occur in many crude oils, and have been considered by some as indicating differences in the source from which the oil has been produced, whilst in all probability they owe their existence to differences in temperature and pressure during the formation of the oil.

The hexane formed in the dissociation of the dodecane by the splitting off of the CH_2 groups that went to form the olefines and naphthenes, on further heating forms still simpler paraffins and olefines, until these also reach the last stage, and are decomposed to carbon and hydrogen. The result is that in a simple cracked spirit we find as the chief constituents all the liquid hydrocarbons of the paraffin, olefine, naphthene and even, occasionally, acetylene series that have boiling points below 150° C.

In the process of cracking an oil, after the light cracked fractions have been distilled off, the residuum is generally high in colour, and when again returned to the cracking system, unless well diluted with fresh oil, is liable to give trouble from the deposition

of pitch and carbon; but it contains not only naphthenes but also heavy hydrocarbon molecules capable of being broken up into naphthenes by further and higher temperatures, and it is worth consideration as to whether it could not be used more profitably for the production of aromatic hydrocarbons.

At the present time the demand for toluene is increased enormously for the manufacture of trinitrotoluene for explosive purposes, whilst if a State-aided attempt is to be made to capture the dye industry, the demand for aromatic hydrocarbons, benzol, toluol, xylol, naphthalene and anthracene, will for some years be far in excess of the supply.

It will be remembered by many that in 1885, when the demand for benzol was high, Nobel Brothers, Liebermann, Burg, Salzmann and Wichelhaus investigated the possibility of obtaining aromatic hydrocarbons from petroleum residues, and obtained excellent results. The slump in the price during the past twenty-five years, which at one time brought benzol and toluol down to something like 6*d*. per gal., led to these processes being abandoned, although I believe the preparation of aromatic hydrocarbons on a small scale is still practised from Russian petroleum.

The residues from the cracking to form motor-spirit at from 500° to 600° C., if they were passed under a slight pressure through a two-inch tube containing a copper spiral to conduct the heat, the whole being heated to 800° to 900° C. and the oil passed slowly through it, would not only crack hydrocarbons to naphthenes, but would convert the naphthenes into aromatic hydrocarbons, the whole range of which would be found in the tar formed. Something like 80 cub. ft. of gas would be produced at the same time per gal. of residue treated, which would be used either as fuel or for the enrichment of water-gas after all benzol and toluol had been scrubbed out of it.

So far I have dealt with the cracking of oil alone, but during the past ten years several processes have been introduced in which steam or water has been introduced with the oil into the cracking ducts, the idea being that hydrogen from the water would affix itself to the heavy hydrocarbons and hydrogenate them into lighter hydrocarbons: to aid this action catalysts have been frequently used, nickel being the most popular.

The idea of the use of nickel as a catalyst is twenty-seven years old, as in 1888 Ludwig Mond took out an English patent, 12608 of that year, in which he mentions the treatment of hydrocarbons together with steam by passing them through heated vessels containing firebrick or iron oxide, and he states that if metallic

nickel is used in place of the iron oxide, then only a moderate temperature is required.

About 1900 Sabatier and Senderens studied the action of nickel and other metallic catalysts on the hydrogenation of oils, and in the following years there were many more patents taken out covering its use. Still later there were a large number of patents taken out in America by Dr. Day, Ellis, Kayser and others, dealing with the use of nickel as a catalyst.

Mond, Sabatier and Senderens all recognised that such surface action as the nickel exercised, took place only at temperatures below at any rate 300° C., but the more recent exploiters of the idea have drifted back to the heats one would use for cracking, not for hydrogenation. It may have been my ill-fortune, but in such experiments as I have made I have got just as much, and sometimes more conversion, when using the oil alone, as I obtained by using water or steam and nickel surfaces at the temperature prescribed (about 600° C.).

When steam or water are used at about this temperature, the residues show signs of being converted more or less into drying oils, and fairly good varnishes can be made from them, which suggests the formation of terpenes, hemi-terpenes or an oxidation of part of the oil.

I have in this paper refrained purposely from saying anything about the latest, and certainly the best, method of motor-spirit production by cracking that I have examined, as the inventor himself has already explained it to you this evening.

DISCUSSION.

The President said the two papers which had been read were obviously complementary one to the other, and he was sure all present would agree that together they formed an admirable exposition of the subject; in fact the exposition was so complete that he ventured to predict that many years would pass before it would be possible to make any useful addition to the statements which had been put forward. Each paper was a model of its kind. In relation to Mr. Hall's paper, he desired to state that it had been delivered under conditions of greater physical difficulty to the author than he had shown or admitted. He (the President) purposely refrained from asking the indulgence of the members on the author's behalf before he read his paper, because he was doubtful as to how far it would be necessary that that indulgence should go. He was glad he said nothing, because the members had seen that

no apology was really necessary. But if no apology had been needed, it was due to the strength of will of the author, which would be appreciated when he stated that two days ago Mr. Hall was almost unable to make himself audible.

The time was so far advanced that he must be very brief in any remarks he made, but he wished to say that what Sir James Dewar and himself were aiming at 25 years ago was not the manufacture of petrol, because at that time petrol was difficult to dispose of in anything like the quantities in which it was necessarily produced in the refining of crude oil for the obtaining of other products. Large quantities of it were used as fuel under the stills, and even larger quantities were burnt to waste. No one knew the prevailing conditions in the Russian oil-fields at that time better than a gentleman whom the members were delighted to welcome at the meeting that evening—Mr. Urquhart—who had been rightly called the hero of the labour troubles which occurred many years ago in Baku, and to whose heroism many of the employees in the oil-fields owed their lives.

The late Mr. Ludwig Nobel informed Sir James Dewar and himself that, in his opinion, the Russian petroleum industry was placed in a disadvantageous position in competing with the American industry in consequence of the fact that the Russian crude oil, which they were working, yielded a very much smaller percentage of kerosene than that which the American refiners obtained, and that the discovery of some process which would admit of largely increasing the yield of kerosene would be one of value. Whilst his colleague and himself were experimenting on the subject, the industrial conditions in Baku were changing, and when they succeeded in showing Mr. Ludwig Nobel how to double the yield of kerosene from Russian oil, he informed them that it was no longer a desideratum to make a change in that direction; that the demand for the heavy residues for fuel had become so much greater than the demand for kerosene that he wished they would go back to the laboratory, and devise a system, not for increasing but for diminishing the quantity of kerosene necessarily separated in giving the fuel oil the requisite flashing-point. His colleague and himself were so discouraged by the response to their efforts that they never attacked that problem, and, so far as he knew, it remained unsolved at the present time.

It was interesting to him to see present at the meeting, in the person of a Member of the Council of the Institution, Mr. T. C. Palmer, a friend to whom Sir James Dewar and himself were greatly indebted for assistance in working out the engineering

details of the plant with which their experiments were carried out. He would have liked to have made some specific references to the exceedingly interesting results given in Mr. Hall's paper, and also to have said a few words on the more theoretical treatment of the subject, which had been given in his inimitable manner by Prof. Lewes, but time did not permit of this. There were several gentlemen present who were competent to contribute to the discussion on the papers, and he would first call upon Dr. Mollwo Perkin, who had done a large amount of practical work in connection with processes of cracking, to give a short account of his experiences.

Dr. F. Mollwo Perkin felt that, after the extremely interesting discourse given by Mr. Hall, which contained so much valuable information, and the very able remarks of Prof. Lewes, there was very little which could be added by way of discussion.

There was, however, one remark Mr. Hall had made, with which he (Dr. Perkin) was not quite inclined to agree, namely, that under no condition could cracking or dissociation of oils be obtained without the deposition of carbon. He thought that, under certain conditions, it was possible to work so that practically no carbon was deposited. Personally he had worked a good deal at a particular process in which the oil was kept in such a condition that vaporisation did not take place at all. That naturally entailed very high pressure, because the process also required high temperature.

If oil was passed through heated tubes at a high temperature, it was necessary, in order to keep it liquid, that the pressure should be above the vapour-tension of the oil. That was pretty considerable at about 600°, but as a matter of fact it might be necessary to have the pressure considerably above the vapour-tension in order to get the desired results. Under such conditions an oil which was not too heavy would pass through the tubes with practically no deposition of carbon at all. He imagined that dissociation somewhat similar to that which took place in Mr. Hall's process occurred, and he thought that the reason why carbon was not deposited was that the oil was kept under high pressure, and was thus prevented from gasifying.

Mr. Hall had referred to the fact that, in passing the oil a second or third time through the process, the results obtained were not quite so good. He agreed with the author that there was a tendency under those conditions to get a very much darker coloured product. There also seemed to be a larger quantity of the terpene-like products to which Prof. Lewes had referred. Any oil which

was to be used satisfactorily in a motor-car must naturally have the terpene products removed, otherwise gumming took place, and the valves became clogged. The removal of the terpenes could, as Mr. Hall had stated, be carried out by the use of sulphuric acid, and to some extent by means of fuller's earth or some other similar substance; but unless the terpene-like products were removed they became oxidised, and the oil was practically useless. That was one of the reasons why cracked oils had got a bad name.

The terpenes might be removed to such an extent that a perfectly colourless oil was obtained which would evaporate without leaving any residue, but if the oil remained in contact with the air, it was sometimes found that oxidation took place, and products were formed of a more or less siccative character, which were very objectionable.

Unless these products could be removed economically from a cracked oil, or unless the oil could be cracked in such a way that the products were not formed, the oil would undoubtedly get a bad name on the market. He had examined the spirit obtained by Mr. Hall's process, and he had not found those objectionable characteristics present.

He had not kept the spirit sufficiently long to enable him to form a mature judgment, and it might happen that perhaps in a year's time it would be found that gumming products had formed in the oil, but Mr. Hall had shown him some samples which he had had in his possession for quite a long time, and in which those products did not appear to be present. No process in which he (Dr. Perkin) or his friends were interested was a rival to Mr. Hall's process, because there was room for everyone.

He certainly thought the product obtained by Mr. Hall was very much better than that which was being produced in America by Mr. Burton. He desired again to express the very great pleasure with which he had listened to both the papers that had been read.

Mr. E. Lawson Lomax said he had listened to Mr. Hall's most lucid and interesting paper with great pleasure, particularly as he had had the opportunity of visiting the works to see the plant in operation. The author had undoubtedly gone very far towards a successful solution of the problem of cracking oils for the production of motor spirit. Only those who had had experience in that branch of the industry could realise what difficulties he had met and overcome, and he desired to wish him every success with his process.

There were one or two points that had been raised in the paper to which he would like to refer. With regard to the question

of running a composite process for the manufacture of motor spirit and oil-gas in gas-works at home, he desired to ask the author whether he had ever considered the possibility of utilising the heavy residues from the first run for motor spirit in the preparation of hydrocarbons of the aromatic series as suggested by Prof. Lewes. It seemed to him that a gas-works was an ideal place for the production of that class of bodies in addition to the amount already obtained from coal. Those bodies, such as benzene and toluene, were of quite as much commercial importance as motor spirit at the present time. There was no doubt that the residues from the first run contained hydrocarbons of the naphthene series, and that they could be profitably further cracked to hydrocarbons of the aromatic series.

The author had mentioned the system of cracking in large stills, and claims had been made for those processes that the spirit obtained contained mostly fully-saturated hydrocarbons. He would be greatly obliged if the author could state whether that was the case, or whether the spirit made approximated in constitution to the spirit made by cracking in tubes.

Turning to the question of the formation of coke, claims had been made by certain inventors that by packing the cracking tubes with certain bodies the formation of coke had been overcome. It had been his own experience, and he thought that of most investigators working on the subject, that, no matter what was the packing of the tubes, or whether oil was used alone or in conjunction with water or steam, carbon was always deposited, and always would be, so long as a complex substance like petroleum was being dealt with. He had not had any experience of the cracking of oils under high pressures, but he could not see that that would affect the matter at all. In the cracking of oils under low pressures or atmospheric pressures, carbon was always deposited.

Then the important question of the unsaturated hydrocarbons produced in the cracking process had to be considered. Although the total percentage of those unsaturated bodies largely influenced the quality of the spirit produced, he thought their constitution played a large part, particularly in regard to the formation of resinous sticky deposits.

With some processes there was an appreciable formation of bodies of the isoprene series $CH_2 = CH - \underset{\displaystyle CH_3}{\overset{\displaystyle |}{C}} = CH_2$ which contained the conjugate double linkage. Those bodies, as was well known, polymerised very readily, and, under certain conditions, spontaneously,

into bodies of high molecular weight. Those polymerisations, however, did not always take the same line, as under slightly varied conditions very different bodies were formed.

Lighter fractions obtained in the cracking of petroleum had been polymerised to rubber-like bodies of the terpene, or hemiterpene series, and to resinous bodies. Some of those polymerised substances were soluble in the cracked spirit, others separated out on standing, but all were detrimental in the use of the spirit in internal-combustion engines, owing to the fact that they caused clogging up of the valves.

Therefore it was essential that as small a percentage as possible of those unsaturated bodies should be produced, as the greater their dilution in the spirit the less easily they polymerised. For that reason the less unsaturated hydrocarbons there were in cracked oils the better it would be. A particularly interesting part of the process was that in which the gases were subjected to pressure before cooling, a largely increased yield of light spirit thus being obtained.

Some time ago he had occasion to examine the permanent gas produced by cracking petroleum, and found that, by passing it through strong sulphuric acid, a portion of the gas was condensed or polymerised to a liquid which consisted of hydrocarbons partly of the saturated naphthene series, and partly of siccative oils of the terpene or hemiterpene series. Again, if the gas was passed through ice-cold bromine, there was a large absorption of gas with very little evolution of hydrobromic acid, a mixture of liquid and crystalline bromides of high molecular weight being obtained.

One of our most eminent organic chemists, with whom he discussed the matter, suggested that possibly a new body had been formed, or at least a body which he believed could exist although it had never been isolated, namely, methylene, CH_2, the first body of the olefine series of hydrocarbons. He did not know whether that was so or not; he could not prove it or disprove it, but he thought it was probable that Mr. Hall was obtaining a similar body or class of bodies which, under pressure, united with each other or with bodies present in the volatile spirit. Some peculiar kind of compound was formed, which was very unsaturated, and would easily combine either with itself to form a larger molecule or with other portions of the volatile spirit, thus increasing the yield of the volatile spirit.

The increased mileage obtained from cracked spirit was, he thought, the sum of various causes. Apart from the higher specific gravity with the same volatility, there was, firstly, the larger

amount of air required for complete combustion; secondly, the proportionately less amount of steam formed during combustion; and, thirdly, the extra amount of heat released during combustion by the rupture of the double bonds of the unsaturated hydrocarbons. Each of those three things accounted, in his opinion, for a part of the increased mileage obtained from such motor spirit.

The President requested those who were debarred by the lateness of the hour from contributing to the discussion to be good enough to send in their remarks in writing, in order that they might be published in the *Journal* of the Institution. He ventured to think there was nothing in the statements of those who had already spoken which needed answering either by Mr. Hall or by Prof. Lewes, and he would therefore conclude the meeting by proposing, on behalf of the members, a very hearty vote of thanks to both Mr. Hall and Prof. Lewes for their exceedingly valuable and interesting papers.

The motion was carried by acclamation, and the meeting terminated, **Mr. A. Duckham** subsequently writing as follows:—

In view of the fact that our Institution is a scientific body, I should have some hesitation in confining my remarks to the commercial aspect of "cracking," were it not that at the Meeting I observed a number of gentlemen who certainly are more interested in this rather than in the scientific side of the question, and furthermore Mr. Hall affords me an excuse in that he mentioned certain prices, e.g. 3*d*. per gal. for gas-oils, 5*d*. per gal. for "cracked" spirit at a gas-works, and 10*d*. per gal. as a comparative price of ordinary motor spirit.

I have had the somewhat unfortunate experience of having lost in one instance some few thousands which I subscribed to further the work of a "cracking" inventor, and subsequently I have had to investigate several "cracking" processes, both on the large scale and in the laboratory, and in each case I have found that, when I am away from the almost hypnotic influence of the enthusiastic inventor, and when I reduce the data which I have obtained to plain pounds, shillings and pence on a commercial basis, I cannot see that these figures justify the investment of capital in the processes in question. The inventors have invariably been gentlemen who in their enthusiasm for their process have been only too ready to adopt optimistic, but not strictly market, figures for motor spirit, and for their crude material.

There is a reflection of the same attitude in Mr. Hall's paper, where he talks about a price of 10*d*. per gal. for motor spirit as compared with 3*d*. per gal. for his crude material, and this at a

time when, although motor spirit is exceptionally high in price, yet it is easily obtainable of the highest quality, and of non-cracked origin, at a price of 7*d*. to 7½*d*. per gal. in bulk in England, whilst at the present time it would be difficult to obtain the crude material for anything under 8*d*. per gal.

Furthermore it has to be remembered that they might have to compete against natural motor spirit at 5*d*. or even less per gallon in bulk, and again that no refined or distilled products of petroleum can ever compete in cost price with natural motor spirit, should it come to keen competition, because motor spirit is the least expensive of all petroleum products to prepare, the cost of fuel being at a minimum on account of the low boiling-point, and the chemical treatment generally *nil*.

It would no doubt be of the greatest interest to many people, if Mr. Hall could see his way to give physical and chemical tests of the various crudes on which he has conducted experiments on the large scale, and of the results that he obtained therefrom, stating the quantity and quality of the various products, with particulars as to loss, and also as to the amount of fuel and stores consumed. An estimate of the allowance which he considers ought to be made for capital, depreciation, repairs, labour, etc., would be necessary to enable one to form some opinion as to the commercial possibilities of his process.

Most of the makers of "cracked" spirit overlook the fact that these spirits are never of quite so high a commercial value as the natural distillate, and this is not only on account of their peculiar smell, but also because of their tendency to deposit varnish-like bodies, which continue to be formed even after very careful refining. Then again some of these "cracked" spirits have such a high specific gravity that an adjustment of the carburettor may be necessary if the spirit is to stand at a level in the jet.

It must not be overlooked that the residual oils which are formed during a "cracking" process are seldom, if ever, of as high a market value as the crude oil on which operations were commenced, and some allowance ought to be made on this account.

A. D.

To these remarks **Mr. Hall** rejoins as follows:

Mr. Duckham appears to be opposed to cracking processes in general, apparently because he lost money in one of them. On the same ground I should be opposed to railroads and mines, for I have lost money in more than one of them.

Mr. Duckham says he has had to investigate several cracking processes both on large and on laboratory scale. I should like him

to name those operated on a large scale which he investigated. It would also be interesting to see the figures which resulted from Mr. Duckham's reduction into £ s. d. "on a commercial basis."

I think the prices that I gave are quite correct: 3*d*. per gal. for gas-oil is the price at which it was quoted in the week's *Oil News*—ex dock. Shortly before the war, gas-oil was being sold at 3*d*. and less, delivered at gas-works in interior towns.

The price of 10*d*. per gal. for petrol which I named was at point of delivery, mostly in interior cities, and ex whatever tax might be imposed. If this motor-spirit was classified as benzol, which it might well be, there would be no tax, and if it were taxed as a gas-house by-product, the benzol now produced at gas-works would also have to be subjected to tax.

Mr. Duckham states that at the present time motor-spirit is exceptionally high in price, yet can be obtained and of the highest quality at 7*d*. to 7½*d*. per gal., bulk in England. If this were the case then the British public should rise in its wrath against the companies who control the price when they exact at retail 1*s*. 9*d*., the retailer's profit being 3*d*., tax 3*d*., and unloading, tinning and delivery, say, 2*d*., making 8*d*. total. Subtracting this from 1*s*. 9*d*. leaves 1*s*. 1*d*., and if, as Mr. Duckham says, it can be freely bought at 7*d*., this would give a profit to the distributors of 6*d*. per gal., or nearly 100% profit. Does anyone believe this is obtained? If Mr. Duckham undertook it as a source of profit, I fear he would fare worse than he did in his cracking investment. No first-quality petrol has ever been offered in bulk at anything like the price which Mr. Duckham names. He further says that it has to be remembered that they might have to compete against a 5*d*. price. He might as well have named 1*d*. or 20*d*.—for it is mere supposition.

When Mr. Duckham says "that no refined or distilled products of petroleum can ever compete on cost price with natural motor-spirit," etc., he is making a very broad statement, and of the kind that has repeatedly been advanced and disproved. I can hardly believe Mr. Duckham such an oracle as able to accurately predict what the future may bring forth. Answering this more in detail, I would say that what he is pleased to call natural petrol, as if it flowed as such out of the ground, is in itself a distilled and refined product, and as it is only a fraction (and a rather small one) out of a long series of refinery products, not even its producers can tell what it costs. It is only what they elect to ask for it that counts.

He is again wrong in saying that petrol is the least expensive of all petroleum products. Gas-oil and fuel-oil are certainly less

expensive, both in production and in transport, and they constitute much larger proportions of the whole.

As to his request for me to give detailed information of my whole business, I must say that, as I am not seeking money for my process, it would be hardly appropriate for me to give any more details.

He states that cracked spirits are never of as high a commercial value as natural distillates. It would have been safer to have said "seldom" than "never." In two important respects some cracked spirits have much greater commercial value, in that of greatly increased mileage and freedom from pre-ignition. Also I can show samples of cracked spirit that possess less odour than petrol, and that have no more tendency to soot. I should like to ask if Mr. Duckham has had any practical experience in operating motor cars on cracked spirits. I have driven on them over 8000 miles, and I cleaned my plugs no oftener than I did with petrol.

There is no need for the gravity of a cracked spirit to be so high as to require any change in the carburettor float. The gravity need be very slightly higher than that of a standard petrol.

W. A. H.

*** Communications are invited in discussion of the following article, which the absence of the author, and a plethora of other contributions, preclude from presentation at a meeting of the Institution.—Ed.

The Occurrence and Distribution of Petroleum and Natural Gas in the Carboniferous Rocks of Kansas and Oklahoma.

By Chas. N. Gould, Ph.D., F.G.S.A., F.Am.Assoc.A.Sci., *Member*.

The oil and gas produced in the Mid-Continent field of Kansas and Oklahoma occurs in rocks of Carboniferous age. The term Mid-Continent field, as used in this article, is intended to include portions of south-eastern Kansas and of northern and north-eastern Oklahoma. The field is roughly bounded on the east by the Ozark Uplift, on the south by the Ouachita and Arbuckle mountains, and on the west by the Permian Red Beds of Kansas and Oklahoma. As here discussed the Mid-Continent field does not include the region adjacent to or south of the Arbuckle or Wichita mountains in southern Oklahoma.

The rocks exposed on the surface in the Mid-Continent field are of Pennsylvanian or Middle Carboniferous (Coal Measures) age, and consist largely of alternating layers of limestones, sandstones and

shales. These formations contain, particularly in the eastern part of the area, a number of coal beds, many of which are of sufficient importance to be worked to profit. The greater part of the combined thickness of these various Carboniferous formations consists of shales. Sandstones are common throughout the area, however, and limestones also occur, especially in Kansas and in northern Oklahoma. On passing southward the various ledges of limestone begin to thin out, and finally disappear, their places being taken by sandstones and shales.

Underlying the Pennsylvanian rocks in this area is the Boone Chert, a formation composed largely of cherty limestone, varying in thickness from 150 ft. to 300 ft. This formation, which is of Mississippian or Lower Carboniferous age, is popularly known to the oil men as the "Mississippi Lime." It is exposed in the region east of Grand River, in several counties in north-eastern Oklahoma, and also in extreme south-eastern Kansas.

Throughout the greater part of the Mid-Continent field the dip of the rocks is to the west or north-west, being monoclinal away from the Ozark Uplift. In the vicinity of Grand River, in south-eastern Kansas and north-eastern Oklahoma, the dip of the rocks varies from 50 ft. to 100 ft. to the mile, north 75° west. On passing westward the angle of the dip gradually diminishes, until at a distance of 100 miles west of Grand River the dip of the Pennsylvanian strata will average 15 ft. to 30 ft. to the mile. The strike of these rocks is approximately north 15° east.

The surface of the region slopes east, the rocks dip west. On passing westward from the western edge of the Ozark Uplift, various higher formations of Carboniferous age appear in successive order. Each younger member overlies the older rocks which are exposed to the east, and which dip beneath the surface and disappear to the west.

In the early history of the oil development in Kansas and Oklahoma no attention was paid to the structure of the rocks. The first wells were located by accident, without any reference whatever to geological conditions. Many of the largest and most productive oil pools in the Mid-Continent field were discovered in this way. Among others so located may be mentioned Glenn Pool, the various pools of the Shallow field, and the Bartlesville, Cushing, and Bird Creek pools in Oklahoma, and such pools as Bolton, Neodesha and Iola in Kansas.

During the past few years, however, much effective work has been done by geologists in this region. For several years the United States Geological Survey has been conducting detailed studies of

this field. The Oklahoma Geological Survey and the Kansas Geological Survey have accomplished far-reaching results. Geologists employed by a number of the larger and more progressive of the oil and gas companies have worked over certain parts of the region very thoroughly. A number of independent oil geologists have, at various times, made observations and reports on specific areas. At the present time, therefore, there is a large amount of accurate data available upon which to base conclusions regarding the relation of the geological structure of the rocks to the oil and gas deposits in the Mid-Continent field.

It will be obviously impossible, within the scope of this paper, to attempt to discuss in detail the structure of all the various oil and gas pools, more than one hundred in number, which have so far been developed in the Mid-Continent field of Kansas and Oklahoma. At this time little more than a hasty bird's-eye view of the situation, and brief comments concerning a few of the larger and more prolific pools, can be undertaken.

The general statement may be made that perhaps two-thirds of all the oil and gas pools thus far developed in Kansas and Oklahoma occur in those localities where there is geological reason for expecting to find oil or gas. Approximately one-sixth of the fields occurs in regions where the geological evidence is negative, that is to say, where the conditions are such that a geologist would not be justified in recommending either for or against drilling. Possibly one-sixth of the developed pools lies in regions where geologists would not expect to find oil and gas, and would recommend that no drilling be done.

By far the greater part of the oil and gas so far produced in the Mid-Continent field has come from ledges of sandstone. These ledges are known to the driller as "oil sands." There is, of course, no virtue in any particular sand *per se*, but any sand that contains oil is an oil sand. Occasionally oil occurs in pervious limestone.

The two factors which appear to be most important in controlling the accumulation of oil and gas throughout the Mid-Continent field are the thickness of the sand and the structure of the rocks.

It has long been recognised by geologists that the sandstone ledges of Carboniferous age, the world over, are notably erratic in thickness. Particularly is this condition true in the Mid-Continent field. This is what might be expected when the nature of the deposits is understood. There is much evidence to show that during Carboniferous times there were in the region discussed extensive mud flats, swamps, lagoons, sand bars and other coastal phenomena. The various sand bars deposited along the margin of

the Carboniferous seas were erratic in thickness, usually varying considerably, even within short distances. These conditions have given rise to what the oil driller knows as "pockety" or "pumpkin-seed-shaped" masses of sand. The geological term employed is "lens-shaped" or "lenticular."

It goes without saying that nothing regarding either the presence or thickness of the sands can be determined by geologists, from the study of surface conditions. Nothing but the drill can reveal these subterranean phenomena. On the other hand, it will be understood that these sands which form the most important reservoirs for the storage of oil and gas occur indiscriminately in the Carboniferous strata, without reference to surface structure. In many cases unusually thick sands have been found to occur in areas where the surface rocks dip normally westward, and a number of the more prolific oil and gas pools in this region have been encountered under conditions of this kind.

In many parts of the Mid-Continent field the normal western dip of the rocks has been interrupted, forming true anticlines. Perhaps more frequently, however, the structure is that of a "terrace" or "arrested anticline." In the Mid-Continent field a true anticline may be said to occur in any locality where the surface rocks dip to the east, or in a direction opposite that of the normal western dip. An "arrested anticline," or "terrace" occurs in those places where the normal western dip of the rocks has been but slightly interrupted, so that the rocks on the surface lie approximately level, but do not dip east.

The geologist in conducting reconnaissance work throughout the region attempts to find eastward-dipping rocks, or in fact rocks dipping in any direction except westward. If pronounced east dips are found to occur in any particular locality, or if an area of level-lying rocks be found, he then proceeds to work out the region carefully, taking precise levels, usually by means of the telescopic alidade. A contour map of the area is prepared, and from a study of this map drilling locations are recommended. Within the past three years many new oil and gas pools have thus been discovered.

To cite a specific instance: There is an area averaging thirty miles wide and about one hundred and fifty miles long, in central Kansas and northern Oklahoma, lying west of the main part of the Mid-Continent field. Within this area there are a number of small anticlinal folds. For a number of years the presence of these folds has been known to geologists. Within the past three years alidade work has been done on several of these anticlines, contour maps have been prepared, and wells located. Up to now seven of

these anticlines have been drilled, and seven oil and gas pools have been discovered. Of these the Newkirk, Ponca, and Blackwell pools are located in Oklahoma; the Dexter, Winfield, Augusta and Elmdale pools are situated in Kansas.

In every one of these seven pools drilling to a depth of 300 ft. or 600 ft. has shown the presence of considerable amounts of gas, and in every case deeper drilling has revealed the presence of oil. On the other hand hundreds of wells have been drilled in this general region, outside the small anticlinal folds referred to, and in no case have these wells encountered either oil or gas in marketable quantities. There are at least three additional anticlines of this general character in this region which have not yet been drilled.

On account of the frequent lack of exposures of well-defined ledges on the surface, and the peculiar erosion encountered in many parts of the Mid-Continent field, it is not always possible to determine, with even approximate certainty, the geological structure of some of the more important pools. Taking into consideration, however, all the known data, the following generalised statements may be made regarding certain of the more prolific oil and gas pools of the two States.

Glenn Pool is largely an arrested anticline, or a region of flat-lying rocks, containing unusually thick sands, which contained very large amounts of oil. The Cushing Pool consists of a series of well-marked anticlinal folds. The structure of this region has been carefully worked out by means of the alidade by the Oklahoma Geological Survey. The Muskogee Pool is located along the western end of a typical anticline. The Cleveland Pool contains several well-defined anticlines and several faults. Boston Pool is anticlinal in structure. Bird Creek and Flat Rock pools appear to contain slight anticlines or terraces. The Bartlesville oil and gas pool contains several anticlines. Hogshooter and Collinsville gas pools are anticlinal. The Shallow field contains several small anticlines, although part of the field contains terraced structure. The greater part of the pools in Okmulgee county appear to consist of small anticlines, often impossible to determine from the surface, with unusually thick sands. In Kansas, the Fredonia gas pool is anticlinal. The Iola Pool appears to be a series of terraces. The Neodesha Pool is a terrace. The Sedan and other Chatauqua county pools contain well-marked terraces and slight anticlines. The Wayside and Bolton pools appear to be terraces.

In the south-eastern part of the Mid-Continent field, extending from Muskogee, south toward McAlester, Oklahoma, and south-eastward as far as Fort Smith, Arkansas, there are a great number of

well-marked and conspicuous anticlines. The region of Pennsylvanian rocks extends beyond the Oklahoma state line into western Arkansas. Throughout this part of Oklahoma and Arkansas considerable drilling has been done, and large deposits of gas have been found in several places. So far as I am informed, practically all the drilling that has been done on anticlinal folds in this region has produced gas. A number of non-productive wells have been sunk, but all of them have been drilled outside the anticlines. Productive gas wells are located at Massard Prairie, near Fort Smith, and at Mansfield, Arkansas, also near Poteau, Spiro, Kinta and Red Oak, Oklahoma. There is little doubt that more extensive drilling throughout this region will reveal the presence of other important fields.

As the result of 15 years' study of the Mid-Continent field it is my best judgment that, at the present time, perhaps one-half of the productive oil territory within the region has been prospected, and perhaps one-fifth of the oil and gas have been taken from the ground. New pools are constantly coming to light. A considerable part of the area has never been thoroughly prospected. I have personal knowledge of at least six regions within the general area that should, when developed, become prolific oil and gas pools. Other geologists who have conducted investigations in this area doubtless know of other localities.

It is not at all improbable that other fields may yet be discovered, equally prolific with Glenn Pool, which has already produced more than 100,000,000 barrels of oil, or with the Cushing field, which for the past six months has averaged over 150,000 barrels of oil per day. Large areas in the Osage Nation, where no drilling has been done, are known to be excellent prospective territory. Other localities located in east-central Kansas show promise of becoming prolific fields. Still other localities in east-central Oklahoma, south of the general field, as at present developed, will doubtless produce vast quantities of oil. While this article is being written, word comes of a very prolific well drilled in on November 13, 1914, near Paden, in western Okfuskee county, Oklahoma. This well is 25 miles from any large pool. It may be the discovery well of another Glenn Pool, or Cushing.

The total amount of the oil produced to date from the various pools of the Mid-Continent field has exceeded 300,000,000 barrels.

For the last five years the amount of natural gas available has varied from 2,000,000,000 to 4,000,000,000 cub. ft. per day. There is little doubt that Oklahoma will continue to produce large quantities of petroleum and natural gas for the next 50 years.